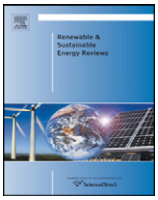
Renewable and Sustainable Energy Reviews 16 (2012) 3481–3506

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Biomass properties in association with plant species and assortments I: A synthesis based on literature data of energy properties

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ARTICLE INFO

Article history:
Received 27 April 2011
Accepted 19 February 2012
Available online 30 March 2012

Keywords:
Principal component analysis
Life-form
Woody species
Herbaceous
C4 plant
CHONSA
Robust model

ABSTRACT

Knowledge of biomass properties and/or fuel characteristics is the basis for bioenergy or chemical conversion processes. Biomass properties are variable and associated with plant species and assortments, therefore, identifying the associations will be important for understanding mechanisms behind the variations and for improvements in predicting biofuel characteristics and management of sustainable feedstock production. A data synthesis was carried out based on data of energy properties including contents of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S) and ash (A) (CHONSA) in variable biomass species and assortments. Data were collected from 260 peer-reviewed literatures and composed of 742 data objects of more than 144 species.

Principal component analysis (PCA) was used to analyze the data. The analyses were carried out at five levels of plant classifications, respectively: levels 1–3 for life-forms, level 4 for assortments and level 5 for species. All the loading plots produced for the energy properties showed the following groupings: C, H and O; ash; N and S. The score plots showed a large natural variation between life-forms for herbaceous materials but more homogeneous for woody ones. Thus, an ordering of energy properties for variable biomass was achieved and correlations between biomass properties and species groups were shown. The general trend was: wood → herbaceous dicots + C4 graminoids → C3 graminoids along the PCA axis from CH rich to ash rich, which is consistent with the empirical knowledge that wood is a high quality but grass a low quality fuel during a combustion. A robust analysis confirmed the findings by PCA. The analyses in this study indicated that the C, H, and O contents are much less variable than those of N, S and total ash. The ash content had the largest role in differentiating biomass energy properties between species and between assortments.

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doi:10.1016/j.rser.2012.02.039

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1. Introduction

Growing concerns about fossil energy and its environmental impact have accelerated the development of bioenergy globally, since biomass is renewable and CO_2-neutral in the long run [1]. The uses of biomass resources for energy purposes will reduce dependency on fossil fuels and is a way of mitigating climate change [2]. The term "biomass" may refer to different materials. This article presents the composition of plant biomass materials as found in the literature and tries to extract conclusions from the data matrices of the concentrations using a multivariate approach.

1.1. Biomass resources for energy

Bioenergy feedstocks include a whole spectrum of plant biomasses, from traditional woody to agricultural by-products and waste. The world bioenergy potential is approximately 1700 EJ y^{-1} from wood and 1200 EJ y^{-1} from herbaceous plants (in grasslands and agricultural areas) [3]. Forest by-products are among the most used resources for bioenergy today. They include logging residues (such as tops, foliage, branches and stumps), wood processing residues (such as bark, edgings, off-cuts, shaves and sawdust) and by-products such as fruit residues (shell, stone, kernel, pit, etc.). According to FAO [4], only 28% of the original tree is processed into lumber or pulp wood, the rest are regarded as residues and can be used for bioenergy, though there is a possible increase in lumber or pulp wood percentage due to more advanced wood industrial technologies in the future.

Agricultural crop residues are another important potential bioenergy resource. There are large quantities of crop residues and leftovers from harvesting such as stalks, leaves, cobs, straw and husks. According to Lal [5,6], the yearly global crop residues are estimated at about 4 Pg for all crops and 3 Pg per annum for lignocellulosic residues of cereals. Based on Koopmans and Koppejan [7] residue-to-product-ratio and data from FAO [4], the authors of this present article get a sum of 6.7 Pg of crop residues (Table 1), of which maize, wheat and rice have the largest proportion. The USA alone has about 0.5 Pg and China 0.74 Pg per year [6,8,9].

Agro-biomass usually has more than one use: as fertilizer (15%), feedstock for papermaking (2.3%) and forage (24%). The rest (58.7%) is currently available as raw material for biofuels [8]. Today, 37% of the world's population (2.5 billion) relies on biomass as their primary fuel for cooking, especially in developing countries [10,11]. Surplus crop residues have been often burned in open air to clear the area for the following season's crop. Such practice continues in many developing countries even today [12] although this causes energy losses and air pollution.

1.2. Biomass properties

Biomass can be converted through different processes into solid (e.g., powder, briquettes, cubes and pellets), liquid (ethanol, propanol and butanol via cellulose process), and gaseous (e.g., methane via anaerobic digestion) fuels [3,6,13,14]. Biomass can also be feedstock for the production of different chemicals through thermal and chemical processes [15]. The design or choice of the processes has to be based on the biomass properties that include physical characteristics such as energy value and chemical ones such as content of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and ash (A), regarded as CHONSA in this study, and even ash composition that will be discussed in another article [287]. These properties may vary considerably with species [16,17], growing environment [18,19], time/age [20,21] and management [22,23]. To be able to use the biomass for sustainable production of biofuel and green chemicals, it is a prerequisite to better understand the impact these fuel characteristics and their variations have on different processes. Biofuel producers and authorities may also want to know the biomass properties such as formation of acid gases by the presence of the elements N and S in thermal conversion of biomass in order to predict, for example, corrosion in boilers and control emissions and their environmental consequences.

Differences in biomass properties or feedstock quality between species can be largely attributed to the nature of the plant that is determined by its physiology and evolution. Plant species have similarities in the basic photosynthetic process for growth and biomass production, but may considerably differ in their physiological pathways in order to adapt to a diversity of environments after a long history of evolution. For example, plant species may vary in photosynthesis efficiency due to different physiological pathways such as C3 (CO_2 is fixed through 3-carbon organic acid) or C4 (CO_2 is fixed through 4-carbon organic acid) cycles [15,24]. Thus, variable biomass properties and, consequently, chemical compositions between species and/or life-forms are expected [15,25]. Identifying these differences and/or similarities in association with species or plant function groups is absolutely necessary. Without this knowledge, it would be impossible to perform basic studies on the mechanism behind the variations and therefore to improve the predictability of biofuel characteristics and/or to manage feedstock production.

Among many biomass properties, the contents of energy-carrying chemical bonds between the most abundant elements C, H, O, N, and S as well as the total ash content contribute the most important data. It is well known that C, H and O proportions in biomass are directly related to the results of photosynthesis and that they are used as major variables in predicting and calculating biomass calorific values [15,26]. The elements N and S are essential in many organic molecules and can form higher energy chemical bonds like C—N, C—S, H—N and H—S than those of C═O, C—O and O—H [27]. For combustion, the contents of N and S may be linked to environmental consequences such as acid rain and smog [28]. Ash content is negatively correlated to the energy value and the ash composition can largely affect performance of biomass conversion processes [15,26].

Biomass properties may vary also within a species. One of the most common phenomena is differences in fuel characteristics between plant organs (i.e., biomass assortments such as leaf, stem, bark and fruit shell), due to an uneven distribution of the organic and inorganic materials in various plant parts [15]. For crop residues, the variations in fuel characteristics can be attributed to breeding efforts for high food yield and agricultural practice.

1.3. Existing knowledge and objective of this study

Knowledge about biomass fuel characteristics is accumulating ([29] and references therein), but mostly based on case studies. Research to determine the relationship between biofuel

Table 1
Crop residues in the world (recalculated using FAO statistics data [4], and Koopmans and Koppejan residue-product-ratio [7]).

Crop	Residue	Production Tg	Crop	Residue	Production Tg
Cassava	Stalks	14.9	Millet	Stalks	56.1
Cocoa	Pods	4.2	Oil Palm	Fiber	29.0
Coconut	Shells	7.2	Oil Palm	Shell	13.5
Coconut	Husks	25.1	Oil Palm	Bunches	47.7
Coffee	Husks	17.3	Rice (paddy)	Husk	181.2
Groundnut	Husks	16.9	Rice (paddy)	Straw	1192.5
Groundnut	Straw	81.7	Soybean	Straw & pods	777.9
Jute	Stalks	8.5	Sugarcane	Tops	504.8
Maize	Stalks	1634.2	Sugarcane	Bagasse	487.9
Maize	Cob	223.1	Tobacco	Stalks, etc.	13.8
Maize	Husks	163.4	Wheat	Straw	1193.4
			Total		6694.3

characteristics and biotic and abiotic factors is rare. Although a number of studies have tried to compile the data and sort out the differences in biomass properties between assortments (e.g. [29]), few studies, if any, have been done to link the fuel characteristics to biological classifications and/or physiological function groups. This report is a synthesis of CHONSA data in association with biological classifications such as life-forms, species groups and assortments and will be followed by another synthesis as a separate study of data about ash composition. Data were collected from 260 peer-reviewed publications and covered 742 data objects for more than 144 species from all over the world. Principal component analysis (PCA) was used to analyze a large amount of data because the issues were multivariate. A vast majority of the original data were related to combustion studies. The direct combustion of solid biofuels to obtain heat and power was the most used technology and covered no less than 14.2% of the global energy used in 2002 [30].

2. Materials and methods

2.1. Data collection

Data pertaining to large number of biomass fuels were collected from the published literature. Three types of literature were investigated: peer-reviewed academic work, scientific reports of well-known research institutes such as NREL in USA and VTT in Finland, and electronic databases PHYLLIS (www.ecn.nl/phyllis) and BIOBIB (www.vt.tuwien.ac.at/biobib/).

The original data of CHONSA were collected with due care to ensure the data resulted from standard methods, including those of the American Society of Testing and Materials (ASTM), European Committee for Standardization (CEN), Association of Official Analytical Chemists (AOAC) and the Swedish Standard Institute (SIS). In the publications (see Appendix A), ash content was usually included in a proximate or ash analysis, C, H, O, N and S in ultimate analyses. The data of chlorine (Cl) and fluorine (F) were not included in this study because of the large proportion of missing data (> 20%). Volatile matters, fixed carbon and moisture were excluded in order to pay more attention to the elements.

Extra care was also taken to ensure the plant names and classifications were correct. Some original publications had to be excluded in this study because the plant names or classifications were unusual (e.g., local names) and could not be scientifically confirmed. In many cases, the original literature provided only part of the information about species. Two major websites were then used to make up the missing information: Global Biodiversity Information Facility (GBIF, http://data.gbif.org/) and Natural Resources Conservation Service, United States Department of Agriculture (USDA PLANTS Database, http://plants.usda.gov). Personal communications with the authors of the original publications were also conducted in several cases to confirm some information about the species. In total, 144 species from about 260 literature sources [37–286] were identified, plus quite a few that had to be identified at the genus or life-form level (such as *Pinus* spp., *Populus* spp., *Eucalyptus* spp., etc.) due to the nature of the original data.

2.2. Nomenclature and classifications

Plant life-forms are an alternative way of classifying plants into the standard family-genus-species classification. The scientific use of life-forms emphasizes plant function in the ecosystems but could also be linked to plant evolutionary histories and might used in association with biomass properties, as indicated by some empirical combustion studies [29]. In the present study, data were sorted according to a hierarchy of plant life-forms (Fig. 1) at three levels. The levels of hierarchy were largely based on phytomorphological and physiological life-forms of the biomass species concerned. At the first level, herbaceous and woody species were first distinguished from each other, beyond which the former was divided into dicots and grass and the latter into needle- and broad-leaved species. Bamboo was treated as an individual group due to its special characteristics. Herbs were composed of dicotyledons while grasses were monocotyledons; needle-leaved species were mostly gymnosperms and broad-leaved ones angiosperms. Furthermore, biomass properties of C3 vs. C4 plants were classified within graminoids, and evergreen vs. deciduous within categories of broad-leaf wood species. Further classifications and subgroups were not possible due to limited data.

Then, the assortments were studied as level 4 and botanical species at level 5.

The assortments were mainly categorized in terms of practical use, but botanical organs were also considered. Among the assortment groups, the fruit residue group was the most diverse. It mainly included hull, kernel, pit, stone, coir, cotton gin trash and fruit outer-skin, but also some olive “husk” (should be fruit skin [130,175]), soya bean fruit skin [29,38] and sunflower “husk” (seed shell). Husk was classified as an independent group in this study and limited for graminoids only. It included bran, rice husk and grain processing residue. All assortments were carefully checked and the misnamed categories or incorrect terms in the original reports were corrected in this study.

The coverage of life-forms and related classifications as well as the assortment groups is presented in Table 2.

2.3. Analysis of data

The data used in this study were multivariate, including 6 (CHONSA) variables and 742 objects (Table 3). In order to handle such a vast amount of correlated data, multivariate data analysis was needed. It can be expected, considering the source of the data, that quite a large amount of natural variation is present. A simple but efficient method of analyzing the data matrices and separating structural information from noise is by using principal component

Table 2
Nomenclature and classification of biomass (see Appendix A for more detailed information about the datasets).

Life-form	Plant family	Assortments	
		In literature	In present study
Broad leaf wood (WB)	Aceraceae, Anacardiaceae, Arecaceae, Asteraceae, Betulaceae, Burseraceae, Casuarinaceae, Dipterocarpaceae, Ericaceae, Euphorbiaceae, Fabaceae, Fagaceae, Juglandaceae, Lauraceae, Lecythidaceae, Malvaceae, Melastomataceae, Meliaceae, Moraceae, Myrtaceae, Oleaceae, Proteaceae, Rhamnaceae, Rosaceae, Rubiaceae, Salicaceae, Sapindaceae, Sapotaceae, Simaroubaceae, Sterculiaceae, Theaceae, Ulmaceae, Vitaceae	• Those directly related to stem-wood: whole tree, wood, shaving, chips, sawdust • Logging residues mostly: tops, stick, branch, pruning, shrub • Bark • Fruit residues: pit, stone, coir, shells, hull, kernel	Wood Log-res Bark Fruit-res
Needle leaf wood (WN)	Casuarinaceae, Cupressaceae, Pinaceae		
Herbaceous, dicot (HD)	Agavaceae, Apocynaceae, Asteraceae, Brassicaceae, Cannabaceae, Chenopodiaceae, Cucurbitaceae, Fabaceae, Lamiaceae, Linaceae, Malvaceae, Pedaliaceae, Polygonaceae, Solanaceae, Tiliaceae	• Whole plant, straw, stalk, corn stover • Stem • Leaf • Fruit residues: shells, cotton gin trash, hull	Straw Stem Leaf Fruit-res
Herbaceous, grass (HG)	Cyperaceae, Poaceae	• Husk • Cob (maize) • Bagasse	Husk Cob Bagasse
Bamboo (BA)	Poaceae	• Bamboo	Bamboo

Bamboo (BA) is treated as an individual group due to special characteristics.

analysis (PCA) [31,32]. Before applying the PCA calculation, the data were variable-wise mean-centered and scaled by the inverse standard deviation of the variables. This operation avoids elements with high concentrations dominating the analysis. Because of the nature of the data, many missing values were present. Objects with too many missing values (>20%) were removed. Algorithms were used that could compensate for a small number of missing values.

PCA was conducted on data matrix that was formed by cases of life-forms/assortments × 6 variables (CHONSA). All selected data were normalized to dry biomass basis before scaling. The PCA analysis was performed using SIMCA P+ (version 12.0.1.0), developed by Umetrics AB, Umeå, Sweden.

A robust analysis was then conducted to reduce the possible influence of outliers and missing values on data during PCA analysis. MATLAB 2008b (www.mathworks.com) and the PLS Toolbox Ver 6.1 (www.eigenvector.com) were used. In addition, averages were compared to examine differences in single variables between plant species and groups.

To examine the importance of ash in the relationships between CHONSA and biomass species, PCA on ash-free data of CHONS and total ash were also performed. The ash-free data of CHONS were scaled to percentage. Averages of the elements for different life-forms and assortments were also compared using both ash-free and none-ash-free data, but some categories had to be excluded due to too limited amount of data (Table 3).

3. Results and discussion

The analyses were carried out at five levels according to the scheme in Fig. 1.

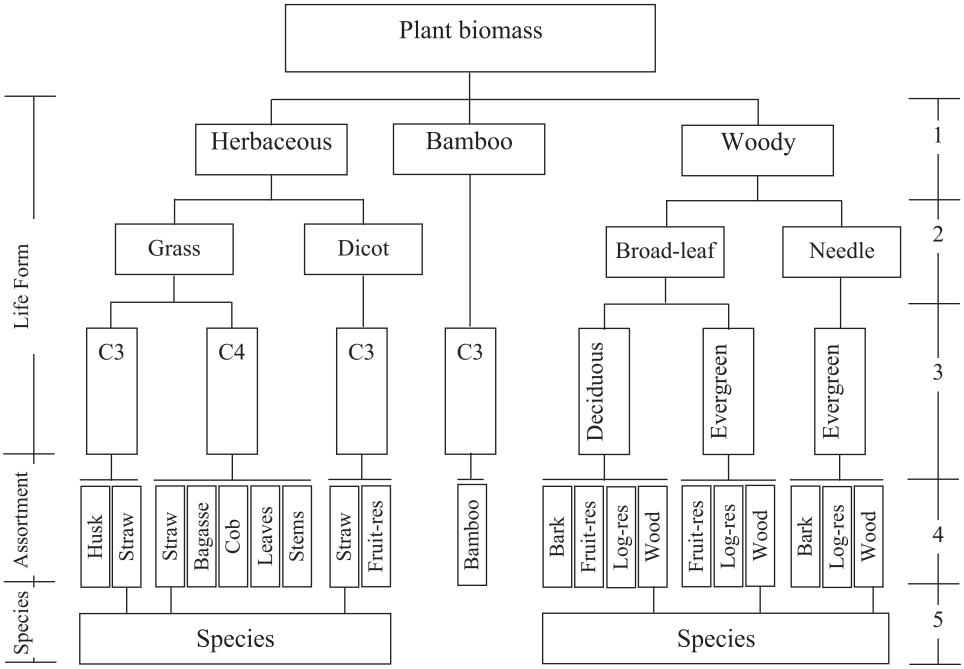

Fig. 1. A schematic layout of the biomass classification system used also for the five-level comparisons in this study.

Table 3
Objects used for analyses in this study.

Group	Ecotype	Assortment	Objects	Group	Ecotype	Assortment	Objects
WB	Evergreen	Fruit-res	64	HG	C3	Husk	36
		Log-res	14			Stem[a]	1
		Bark[a]	1			Leaves[a]	1
		Leaves[a]	1			Straw	111
		Wood	43		C4	Straw	72
	Deciduous	Bark	8			Bagasse	29
		Fruit-res	43			Leaves	4
		Log-res	26			Stems[a]	2
		Wood	76			Husk[a]	1
WN	Deciduous	Bark[a]	1			Cob	13
		Wood[a]	1	HD	C3	Straw	67
	Evergreen	Bark	19			Stem[a]	1
		Log-res	7			Leaves[a]	1
		Fruit-res[a]	1			Fruit-res	27
		Leaves[a]	1	BA	C3	Bamboo	14
		Wood	56		Total		742

[a] Not included in Section 3.3.

3.1. PCA based on CHONSA content

3.1.1. Level 1: differences between woody and herbaceous life-forms

PCA on 742 × 6 matrix of CHONSA content data was carried out. The first four principal components explained 39.7%, 25.0%, 14.9% and 10.9% of the variation in fuel characteristics, respectively. Fig. 2 shows the score plot (I), loading plot (II) and contribution plot (III) for the first two components. The plots with third and fourth components were complicated and contained less structure.

The woody and herbaceous species are presented using different type and color dots in the score plot of the first (PC1) and the second (PC2) principal component. A trend was found: the woody group was more concentrated at the positive end of PC1 and the herbaceous followed in a wide-spreading trend towards the other direction. The trend can be mostly attributed to ash and carbon contents as indicated by the corresponding loading plot (Fig. 2-II), where the energy elements C and H forms a group at the positive end and ash in the other direction of PC1. The contribution plot (Fig. 2-III) also suggests the importance of C and ash content, i.e., the variables that stretch the first PCA component. From these results, the general trend seems to be that woody species have lower ash content and higher content of carbon than herbaceous species. Moreover, according to the first PCA component, woody species tend to also have lower contents of N and S and higher contents of O and H.

Both the woody and the herbaceous group contained life-form subgroups and various assortments. Further explorations were therefore conducted at other levels.

3.1.2. Levels 2–4: variations within the herbaceous life-form

After the general comparison of woody, herbaceous and bamboo groups at level 1, a more detailed study at other levels was warranted. The PCA models were repeated on appropriate subgroups of the whole data set. Three comparisons were made for sub-groups of herbaceous life-form group.

Level 2: herbaceous dicots vs. graminoids (96 vs. 270 objects)
Level 3: C3 vs. C4 species of graminoids (149 vs. 121 objects)
Level 4: assortments of all herbaceous species (366 objects)

The generated three PCA score plots showed some patterns and their corresponding loading plots (Fig. 3a2, b2, c2) were more or less similar to each other and also similar to Fig. 2-II but rotated. The PC1 of the loading plot was a general energy content direction. Carbon (C) and hydrogen (H) are grouped in one direction, representing high energy, opposite to ash (A) representing low energy. S and N groups were at the positive end in the second component (PC2) and O in the opposite direction. The first and second principal components together explained the most variation (>63%) in all the three cases.

Graminoids could not be significantly distinguished from herbaceous dicots (Fig. 3a1). although there was a two-group pattern, HG and HD were involved in both. Two groups can be rather clearly seen on the score plot for C3 and C4 plants (Fig. 3b1), where the group at the positive end of PC1 (more ash) is almost composed of C3 plants only while the group at the negative end of PC1 (more energetic) is composed of both C4 and C3 plants. The pattern in score plot Fig. 3b1 at least partly explained the pattern in Fig. 3a1 as well as the pattern of herbaceous group seen in Fig. 2(I). That is, there seemed to be a transition from herbaceous dicots + C4 graminoids to C3 grass along PC1 from a CH-rich to an ash-rich direction.

As shown by the loading plot (Fig. 3b2), C4 plants were closer to C and H along the PC1, thus indicating low ash content. However, a part of C3 was mixed. This is probably explained by the facts that C4 plants exhibit high photosynthesis rate since they can efficiently take up CO_2 even at high light saturation and low CO_2 compensation points [15,24,33]. Indeed, C4 species seem to have a lower ash content on average than C3 ones, as indicated in Section 3.3 of this study (see Figs. 4 and 5).

PCA on assortments of herbaceous species also generated some grouping (Fig. 3c1). Bagasse, maize cob, and a part of fruit residues and straw together formed the group to the left of the score plot along the PC1, while husk grouped alone on the right towards the positive direction of PC1. It is of note that straw mixed with all the other assortments and was spread all over the score plot, from left to right along PC1 and from bottom to top along PC2. Bagasse, maize cob and most fruit residues hold characteristics of high C and H and low ash (Fig. 3c2, see also Figs. 4–6), in contrast to husks that distributed rather independently from maize cob and bagasse. Leaves and stems had a small number of sample points and were not compared with other assortments. Score plot 3c1 what could be seen for Fig. 2-I, the assortments did contribute to the large variations for the herbaceous group, but did not influence the relative positions of HD, C4 and C3. There are two groups of straw in score plot 3c1, corresponding to C3 and C4 patterns in Fig. 3b.

3.1.3. Levels 2–4: variations within the woody plant group

Following the same procedure as for the herbaceous groups, three comparisons between the sub-groups of woody species were performed using PCA:

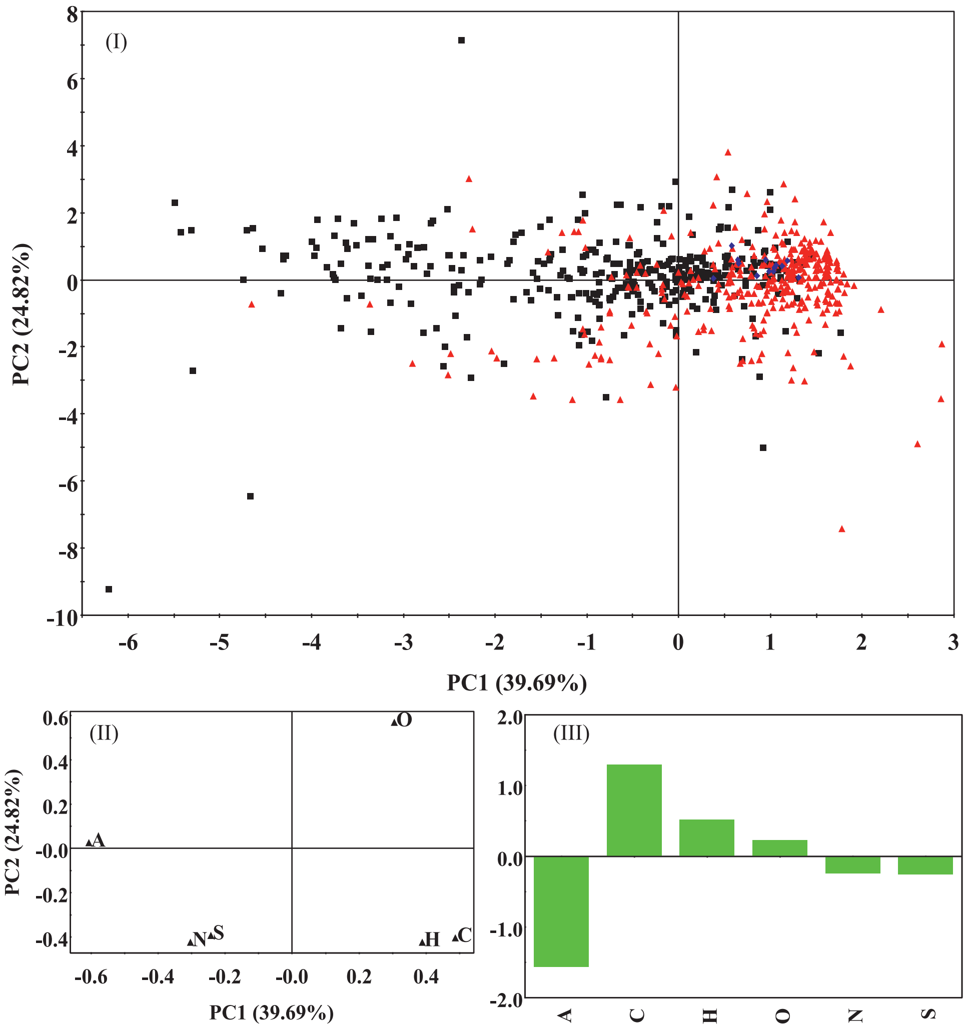

Fig. 2. PCA results (based on all data in Appendix A) for herbaceous and woody groups based on CHONSA contents in biomass. I, score plot; II, loading plot; III, contribution plot, herbaceous against woody biomass (■ herbaceous; ▲ woody; ◆ bamboo). There is a contrast between ash (negative) and the energy-rich compounds C, H and O (positive) along component PC1 in the loading plot. The high spread along component 1 for both groups is due to the presence of different life-form subgroups and assortments.

Level 2: broad- vs. needle-leaved life-forms
Level 3: deciduous vs. evergreen broad-leaf trees
Level 4: assortments of all wood species

The three matrixes included 362 × 6 data points for broad-leaved (276 objects) vs. needle-leaved group (86), 276 × 6 for deciduous (153) vs. evergreen broad-leaved trees (123) and 362 × 6 for woody assortments. The PCA score plots based on different models did not show any significant grouping pattern, i.e., dots of the subgroups were spread in mixture for all the three comparisons. These results suggest many similarities in the examined variables (CHONSA) between needle-leaved and broad-leaved trees, between evergreen and deciduous broad-leaved trees, and also between those assortments. The results are also in agreement to the results shown in Fig. 2 where the woody group had a denser cluster.

3.2. Robust analysis: for levels 1–4

Data were taken from the literature and this means that percentages and concentrations from different sources were combined. The data were expected to contain outliers based on printing errors, analytical errors, different definitions, different analysis techniques etc. The figures in the previous sections clearly show that outliers in the data exist, suggesting that a robust data analysis was needed. In univariate data analysis, robustification can be obtained by trimming, e.g., leaving out the highest and lowest 2.5% of the distribution. With correlated multivariate variables, this is an impossible task and is where multivariate robustification comes in. The technique uses PCA analysis. The PCA model for a number of components provides a residual distance to model and a distance to model (leverage or Hotelling distance). It is possible to do the trimming on these values by leaving out the objects with the highest Hotelling distance and those with the highest residual distance. In this way, a more robust PCA model can be obtained where the components are less prone to error because of outlier influence.

The technique of robustification was applied to the CHONSA data using a 4-component PCA model. 652 objects out of 742 were left (87.9%). The model recalculated on the robustified, mean/centered and scaled data gave one important component explaining 43.9% of the total sum of squares. In this component, certain important trends in the data can be seen in Fig. 4. The loadings showed a contrast between ash and the CHO group as expected and seen earlier in this paper, with ash in the positive and CH in the

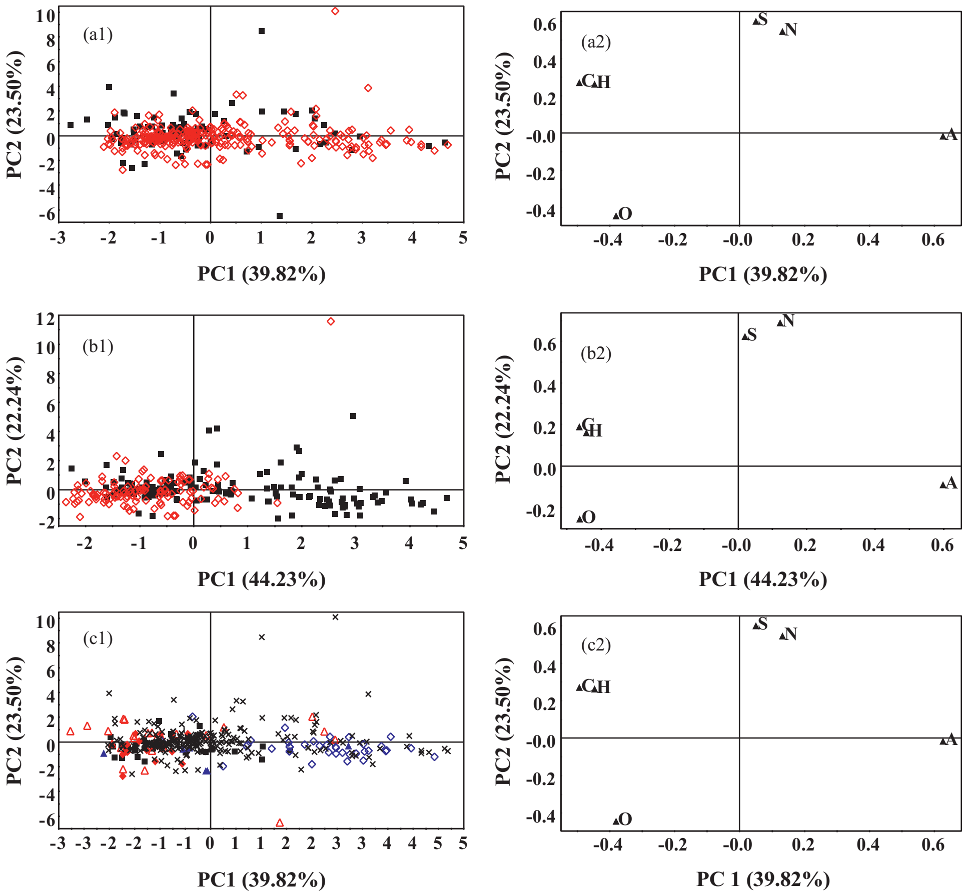

Fig. 3. PCA plots for herbaceous species based on CHONSA contents in biomass (Appendix A): (a) herb dicots (HD ■) vs. graminoids (HG ◇), (b) C3 (■) vs. C4 (◇) species under graminoids and (c) assortment of all herbaceous species (bagasse ■, maize cob ◆ , fruit residue △, husk ◇ , leaves ▲, stem |, and straw ×).

negative directions. In Fig. 4, the first PCA scores are shown with the different materials grouped. It can be seen that some groups are dense while others have large internal variation. Furthermore, some groups are centered around the zero line and others are far from it.

The husk of C3 graminoids tended to be significantly far from the zero line, towards the positive direction of PC1, and rather separated from straw of C4 grass, bagasse, maize cob, bamboo and most woody assortments (except for fruit residues of evergreen WB). Most woody groups were situated near and below zero. In general, woody groups seemed to be more concentrated than herbaceous assortments, but there is no significant difference between the groups. These results are consistent with those in the previous section. The pattern in Fig. 4 has much similarity to that in Fig. 5, showing a trend of ash reduction in biomass from herbaceous to woody species.

3.3. *Role of variations in ash content on biomass properties*

C, H and O are directly captured by plants during photosynthesis from the air and water, while N and S are obtained via different processes from the soil. To study how these energy elements vary fundamentally with plant species, a comparison analysis was made using ash-free data.

PCA based on ash-free data of CHONS did not show any significant grouping, no matter what level the comparisons were made.

Similar results were obtained by comparing the averages with and without ash-free data (Fig. 6). The differences in C—H—O between the groups or subgroups were much smaller with ash-free data than those with non-ash-free data. In contrast, ash did not play a significant role in variations in biomass N and S contents; the large differences between life-forms and assortments remained even when ash-free values were used.

The results that energy elements did not vary as much as ash content suggest the importance of ash in differing biomass categories.

At the species level (Level 5), the importance of ash in variation of biomass energy properties can be illustrated. Fig. 7(a) and (b) shows total ash contents in straws of herbaceous species and stem wood of tree species, respectively, and their corresponding carbon contents in Fig. 7(c) and (d). In contrast to the tree species, ash and carbon contents were more variable in herbaceous species. These results corroborate those found in previous sections.

4. Conclusion and general discussion

A large set of data on percentages of CHONSA was collected for all possible species and assortments found in the literature. The amount of missing data and the natural variation expected required a multivariate analysis by PCA. This multivariate approach was demonstrated not only to show groupings and relationships between the groups in score plots, but also to interpret the discovered relationships using the loading plots. PCA models can be

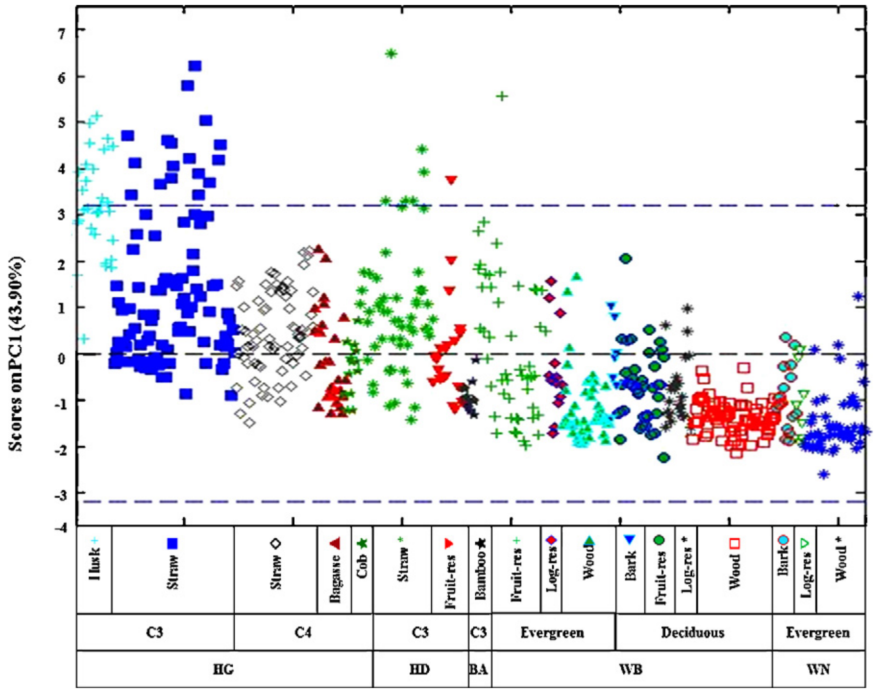

Fig. 4. Robust analysis for CHONSA. Above the zero line indicates more ash and below it indicates more CHO. The biomass categories with less than 3 objects (observations) are not illustrated.

made on whole data sets and also on well-selected subsets. All produced loading plots for the analyzed data (CHONSA) showed the grouping CHO vs. ash vs. NS. The score plots showed a large natural variation between life-forms for some (e.g., herbaceous) materials while others (e.g., woody) were more homogeneous in these properties (Figs. 2 and 4). Thus, an ordering of biomass properties for variable biomass spectrum was achieved and correlations between biomass properties and species groups were shown. The general trend was: woody → herbaceous dicots (HD) + C4 graminoids (HGC4) → C3 graminoids (HGC3) along the PCA axis from CH rich to ash rich, which is consistent with the empirical knowledge that wood is a high quality but grass a low quality fuel when combustion is concerned.

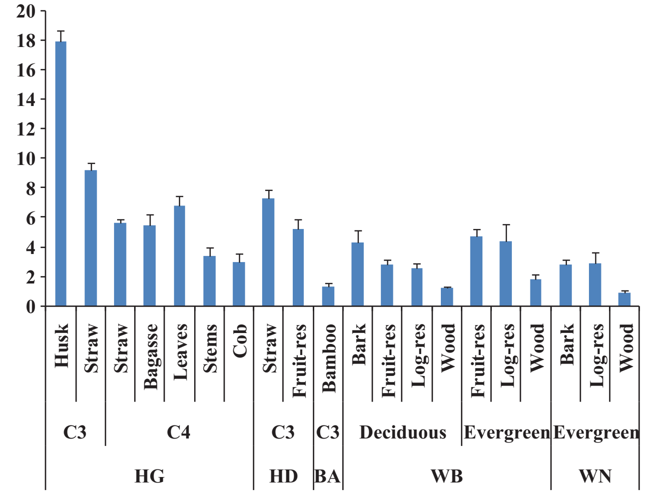

Fig. 5. Average ash content (%) in different biomass groups. The number of objects can be found in Table 3. The categories with less than 3 objects (observations) are not included.

A robust analysis confirmed the general patterns by PCA. Herbaceous biomass such as straw, fruit residues and maize cob showed a high natural variation, while woody materials were below average in ash content and very homogeneous in composition.

The contents of CHONSA in biomass can be attributed two basic approaches: the uptake of CHO is via photosynthesis from air and water while N, S and ash elements are obtained by other processes from the soil. The analyses on as many as 742 objects of more than 144 species in this study indicate that CHO contents are much less variable between species categories and between biomass assortments than the rest. The ash content has the largest role in differentiating biomass energy properties and fuel energy content between species and between assortments. This conclusion was proposed by some scientists 1998 [15], but had not been proved by large data before this current study.

The mechanisms for the general trend found in this study may be explained in many ways but the data in the present study are not sufficient to elucidate many explanations. Wood has longer life-spans than herbaceous species. With a longer development period of up to ten-fold or even hundred-fold, woody species accumulate many more carbohydrates than herbaceous ones. In contrast, herbaceous biomass is often a product from one growing season. Plant photosynthetic process may be an important explanation for the pattern observed for C4 and C3 plants. C4 plants have a higher photosynthetic rate and therefore, result in a larger accumulation of carbohydrates than C3 ones [15,24]. However, the fact that herbaceous dicots tend to have higher CH but lower ash content than graminoids (monocots) suggests that reasons other than photosynthesis need to be explored in the future. Studies have shown that herbaceous dicots have a generally lower quantum yield of photosynthesis than monocots, regardless of whether they are C3 or C4 [33,34]. The photosynthetic process can involve a large number of different complicated processes of plant life, which may vary with the

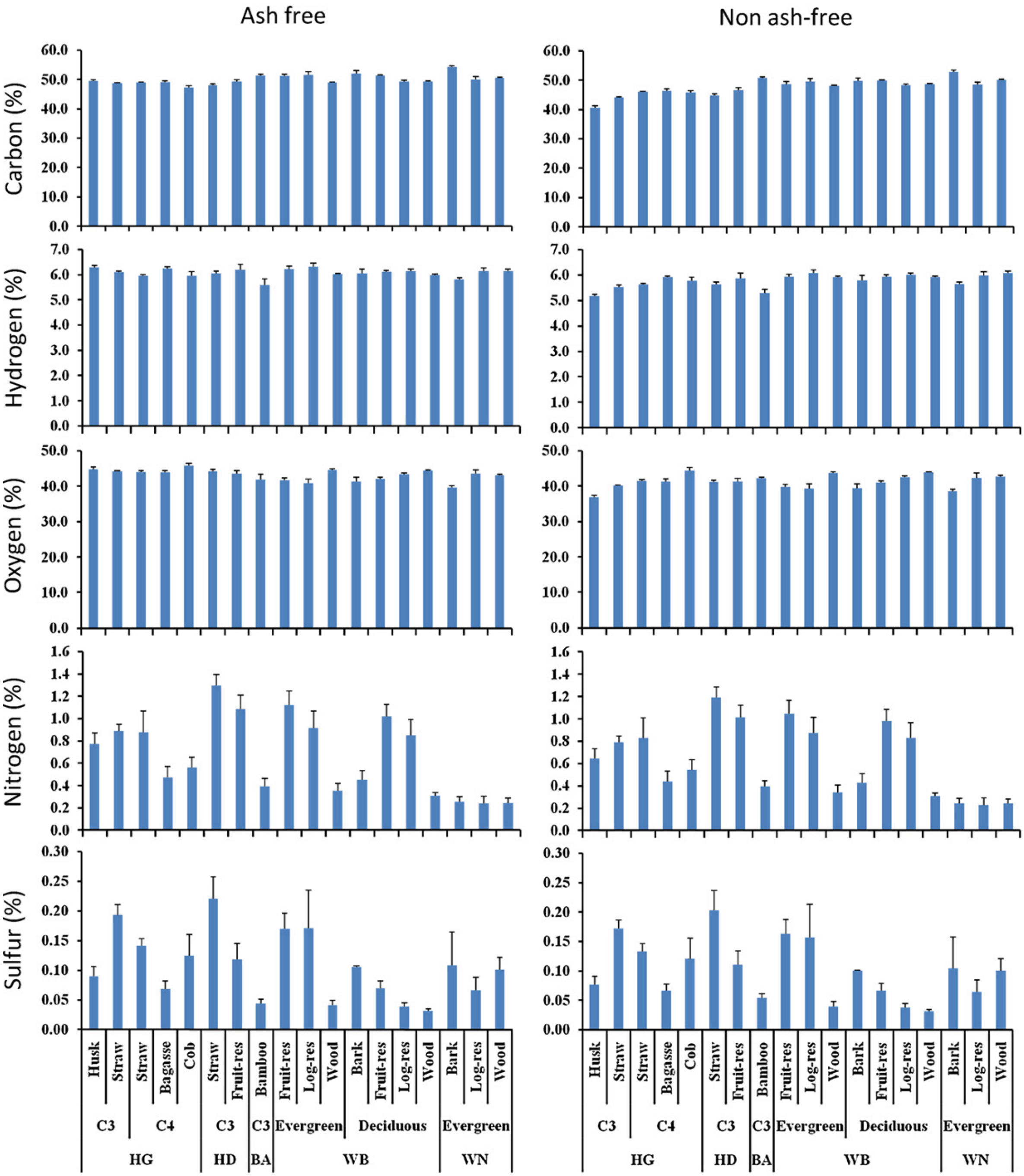

Fig. 6. Average of carbon, hydrogen, oxygen, nitrogen and sulfur content in ash free vs. none ash-free data. The biomass categories with less than 3 objects (observations) are not illustrated.

environment such as light, CO_2, temperature, water and nutrient [24,35]. As ash is involved, processes related to mineral uptake from the soil and distribution of the materials in plant tissues must be important. Uptake of mineral elements may be affected by many factors such as soil type, soil pH, and ion concentrations among others [36]. Furthermore, management in production (e.g., cropping) and feedstock handling may also play a role.

The fact that ash has a more profound role than CHO in influencing variability of fuel energy properties suggests an importance in studying ash composition of biomass. As a follow-up to this current study, variations in ash composition in correlation with species will be illustrated in a follow-up paper [287]. This study suggests that research efforts in selecting and improving biomass feedstock for high energy values must consider parameters other than total CH content only. In this respect, a proportion of organic components with high energy chemical bonds may be more important than CH content.

Nevertheless, to our knowledge, this study is the first to examine the relationships between energy property elements and biological classifications. Many scientific questions still remain to be answered. This study focused on biofuel energy property variations of different life-forms and species with variable

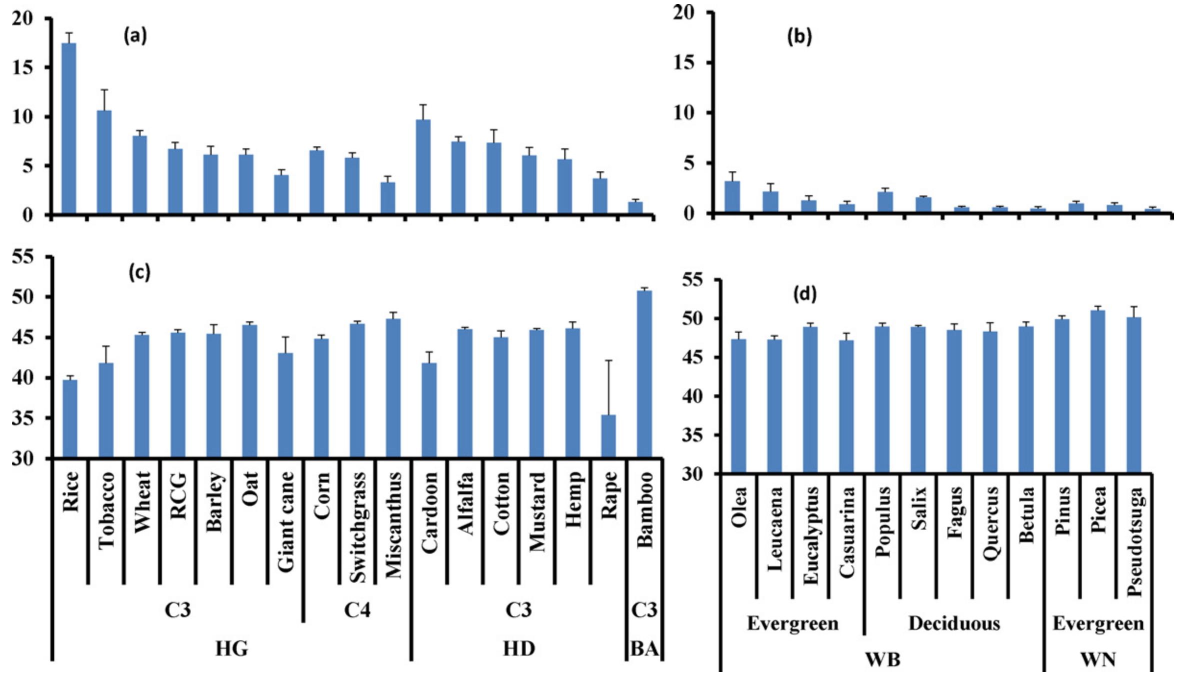

Fig. 7. Ash and carbon content (%) in straw and stem wood biomass of different species: (a) ash in straw, (b) ash in stem wood, (c) carbon in straw, (d) carbon in stem wood. Bars refer to mean + standard error (se). Species and categories with less than 3 objects (observations) are not included. RCG: reed canary grass.

genetic backgrounds and evolutionary histories. In order to attain sustainable biofuel production, future studies must include the effects of environment, temporal factors and management on fuel characteristics. This study also showed how important it is to have access to a complete, universal and error-free database. This would further improve the possibility to predict biomass properties and fuel characteristics for energy industries.

Acknowledgements

The authors would like to thank the Royal Swedish Academy of Engineering Sciences (IVA) for financing Dr Tao within the CAE-IVA Scientist Exchange Program. The authors are also grateful to the financial support provided by the EU Executive Agency for Competitiveness & Innovation (EIE/07/073/Encrop), Swedish Energy Agency (30709-1), EU European Regional Development (project Bioenergigårdar i ett nytt landskap) and the project Bio4Energy.

Appendix A.

CHNOSA content in dry biomass (%).

Category	A	C	H	O	N	S	Sum	Reference
BA-C3-Bamboo (*Phyllostachys nigra*)-Bamboo[a]								
	0.95	51.19	5.29	42.12	0.29	0.03	99.87	[49]
	1.25	51.22	4.90	41.98	0.55	0.05	99.95	[49]
	0.47	51.39	5.25	42.61	0.21	0.03	99.96	[49]
	0.85	52.28	5.09	41.10	0.59	0.05	99.96	[49]
	0.96	51.84	5.18	41.33	0.60	0.05	99.96	[49]
	0.94	51.89	5.21	41.52	0.40	0.04	100.00	[49]
	1.15	51.07	4.51	42.91	0.32	0.05	100.01	[49]
	0.59	50.85	5.40	42.75	0.38	0.04	100.01	[49]
	0.87	51.70	5.00	42.11	0.30	0.03	100.01	[49]
	3.91	47.65	5.77	44.23	0.27	0.11	101.94	[111]
	0.11	51.58	5.16	41.85	0.40	0.04	99.14	[125]
	1.90	48.46	5.98	43.26	0.29	0.10	100.00	[188]
	1.95	48.76	6.32	42.77	0.20		100.00	[26]
	2.54	50.81	5.14	40.89	0.77	0.08	100.23	[210]
HD-C3-Alfalfa (*Medicago sativa*)-Straw								
	5.27	47.17	5.99	38.69	2.68	0.20	100.00	[37]
	5.00	45.80	5.40	41.50	2.20	0.10	100.00	[44]
	10.30	45.10	4.97	35.60	3.30	0.16	99.43	[56]
	9.40	45.00	6.00	36.90	2.50	2.00	101.80	[57]
	8.40	46.70	5.90	35.60		0.25	96.85	[100]
	7.25	46.76	5.40	40.72	1.00	0.02	101.15	[108,114]
	6.52	45.35	5.75	40.24	2.04	0.10	100.00	[182]
	6.50	45.40	5.75	40.20	2.04	0.10	99.99	[182]
	8.40	46.70	5.90	35.60	3.10	0.25	99.95	[270]

HD-C3-Bean (*Phaseolus vulgaris*)-Straw							
5.93	42.97	5.59	44.93	0.83	0.01	100.26	[108,114]
HD-C3-Buffalo gourd (*Curcurbita foetidissima*)-Straw							
4.70	43.93	6.19	42.41	2.48	0.26	99.97	[29]
HD-C3-Calotropis procera (*Calotropis procera*)-Straw							
17.66	34.37	4.92	41.46	1.60	0.02	100.02	[207]
HD-C3-capsicum pepper (*Capsicum annuum* L.)-Straw							
19.90	30.36	3.62	43.92	1.85	0.35	100.00	[272]
5.41	46.09	4.12	43.10	0.95	0.32	100.00	[278]
HD-C3-Cardoon (*Cynara cardunculus*)-Straw							
6.30	40.70	5.68	46.25	1.19	0.11	100.23	[65]
8.90	44.60	6.20	38.59	0.76	0.17	99.22	[66]
8.40	42.78	4.40	43.69	0.64	0.09	100.00	[172]
19.00	39.40	4.70	35.76	0.98	0.16	100.00	[189]
8.90	42.13	4.50	42.53	0.96	0.11	99.13	[197]
12.68	34.14	5.24	46.07	1.75	0.12	100.00	[28]
7.49	43.96	6.07	41.74	0.63	0.11	100.00	[259]
5.90	46.80	5.80	40.70	0.70	0.13	100.03	[261]
HD-C3-Clover (*Trifolium* spp.)-Straw							
2.50	44.90	6.80	43.30	2.20	0.30	100.00	[63]
HD-C3-Cotton (*Gossypium hirsutum*)-Fruit-res							
3.44	48.67	8.11	38.43	1.35	0.00	100.00	[29,53]
2.80	48.50	6.12	41.50	0.97	0.10	99.99	[58]
16.38	42.80	5.40	35.00	1.40	0.50	101.48	[41,90,186]
17.60	39.59	5.26	36.38	2.09	0.00	100.92	[108,114]
1.61	42.66	6.05	49.50	0.18		100.00	[26,114]
13.30	41.23	5.03	34.00	2.63	0.00	96.19	[148,149]
5.40	42.70	6.00	49.50	0.10		103.70	[176]
HD-C3-Cotton (*Gossypium hirsutum*)-Straw							
7.44	45.29	5.79	40.66	0.55	0.27	100.00	[81]
1.91	48.67	5.96	43.05	0.25	0.15	100.00	[97]
5.10	47.07	4.58	42.29	1.04	0.00	100.09	[98]
3.15	47.58	5.96	42.94	0.25	0.12	100.00	[99]
17.30	39.47	5.07	39.14	1.20	0.02	102.20	[108,117,120]
6.68	43.64	5.81	43.87	0.00	0.00	100.00	[114]
17.20	39.47	5.07	38.09	1.25	0.02	101.10	[26,114,192]
4.33	47.10	5.68	42.07	0.63	0.20	100.00	[116]
3.01	41.49	6.20	47.49	1.81		100.00	[124]
4.67	46.47	5.75	41.80	1.09	0.22	100.00	[134,145]
17.20	45.50	6.01	30.08	0.98	0.23	100.00	[149,179]
4.67	42.20	6.00	45.71	0.70	0.39	99.67	[164]
5.99	46.86	6.86	38.98	1.03	0.29	100.00	[218]
5.93	47.41	3.66	48.95	0.81	0.34	107.11	[278]
5.10	47.08	4.58	42.19	1.04	0.00	100.00	[282]
HD-C3-Flax (*Linum usitatissimum*)-Straw							
1.81	50.30	6.10	41.12	0.60	0.07	100.00	[44,59]
2.93	49.10	6.10	40.45	1.30	0.12	100.00	[44,59]
HD-C3-Groundnut (*Arachis hypogaea*)-Fruit-res							
3.37	49.19	7.25	39.04	1.16	0.02	100.02	[29,53,54]
5.89	45.77	5.46	39.56	1.63	0.12	98.43	[108,114]
8.15	47.60	5.35	37.06	1.65	0.18	100.00	[109]
5.70	48.59	5.64	39.49	0.58		100.00	[26,114]
3.10	33.90	1.97	59.93	1.10		100.00	[124]
5.90	48.30	5.70	39.40	0.80		100.10	[176]
HD-C3-Hemp (*Cannabis sativa*)-Straw							
6.90	44.80	5.17	41.90	0.99	0.07	99.83	[56]
6.00	44.30	5.34	42.90	0.85	0.20	99.59	[60]
7.80	45.30	5.91	40.80	1.26	0.14	101.21	[56]
1.60	48.80	5.80	43.50	0.30	0.06	100.06	[89]
5.90	47.20	5.70	40.40	0.80	0.08	100.08	[89]
HD-C3-Jute (*Corchorus olitorius*)-Straw							
1.20	47.79	6.61	42.63	1.77		100.00	[124]
0.64	49.79	6.02	41.37	0.19	0.05	98.06	[141]
HD-C3-Kenaf (*Hibiscus cannabinus*)-Straw							
3.63	46.60	5.80	42.83	1.00	0.14	100.00	[29,44,59]
HD-C3-Knotgrass (*Polyganum aviculare*)-Straw							
5.90	47.10	5.41	39.90	1.08	0.12	99.51	[56]
HD-C3-Lupin (*Lupinus* spp.)-Straw							
22.90	34.40	3.76	36.70	1.50	0.18	99.44	[56]
HD-C3-Mint (*Mentha* spp.)-Straw							
10.78	45.22	5.52	35.76	2.47	0.25	100.00	[37]
HD-C3-Mustard (*Brassica carinata*)-Fruit-res							
4.13	44.20	8.82	42.85	0.38	0.19	100.58	[29,53]
HD-C3-Mustard (*Brassica carinata*)-Straw							
7.70	46.30	6.10	38.30	0.70	0.49	99.59	[66]
5.21	45.70	5.99	41.70	1.06	0.31	99.97	[84]
5.21	45.72	5.99	41.72	1.06	0.30	100.00	[84,242]
HD-C3-Oreganum (*Oreganum vulgare*)-Straw							
4.00	42.50	6.00	46.51	0.70	0.29	100.00	[132]
4.40	42.50	6.00	42.16	0.70	0.29	96.05	[164]

HD-C3-Pigeon Pea (*Cajanus cajan*)-Straw							
1.01	38.05	6.15	53.78	1.01		100.00	[124]
HD-C3-Rape (*Brassica napus*)-Straw							
4.70	46.22	6.10	42.41	0.48	0.10	100.00	[29,45]
5.50	51.10	6.44	34.00	2.30	0.40	99.74	[56]
5.00	47.50	5.99	40.85	0.76	0.29	100.38	[128,129]
4.65	46.17	6.12	42.47	0.46	0.10	99.97	[212]
HD-C3-Safflower (*Carthamus tinctorius*)-Straw							
4.65	41.71	5.54	46.58	0.62		99.10	[108]
HD-C3-Sesame (*Sesamum idicum* L.)-Straw							
6.63	48.95	5.69	38.15	0.58		100.00	[156]
HD-C3-Sisal (*Agave sisalana*)-Leaves							
7.20	47.00	5.70	39.90	0.14	0.03	99.97	[158]
HD-C3-Sisal (*Agave sisalana*)-Stems							
6.10	47.00	6.00	39.10	1.66	0.13	99.99	[158]
3.10	48.00	6.00	42.70	0.10	0.03	99.93	[158]
HD-C3-Soya bean (*Glycine max*)-Fruit-res							
5.44	42.93	6.34	44.35	0.85	0.09	100.00	[29,53]
HD-C3-Sugarbeet (*Beta vulgaris*)-Straw							
4.80	44.50	5.90	42.80	1.84	0.13	99.97	[56,148]
4.00	47.40	5.80	41.40	1.40	0.05	100.05	[41,72,220,227,229]
2.09	50.33	4.90	42.10	0.59	0.00	100.00	[53]
HD-C3-Sunflower (*Helianthus annuus*)-Fruit-res							
3.00	52.90	6.58	35.90	1.38	0.15	99.91	[56,148]
4.20	48.90	6.03	39.70	0.86	0.19	99.88	[58]
3.10	50.80	6.00	39.30	0.59	0.12	99.91	[56]
3.10	51.33	6.43	38.14	1.00		100.00	[110]
1.62	50.37	5.62	42.64	0.33	0.05	100.63	[111,227]
2.70	46.51	5.94	43.40	1.17	0.29	100.00	[215]
4.62	49.66	5.82	38.96	0.59	0.11	99.76	[227]
4.17	48.14	5.56	41.47	0.46	0.10	99.90	[227]
4.00	47.40	5.80	41.30	1.40	0.05	99.95	[41,227]
1.60	50.48	5.82	43.33	0.49	0.11	101.83	[227,228]
HD-C3-Sunflower (*Helianthus annuus*)-Straw							
3.50	60.30	7.13	26.80	2.00	0.12	99.85	[56]
11.78	36.10	5.30	38.95	1.30	0.59	94.02	[164]
HG-C3-Agropyron (*Agropyron* spp.)-Straw							
6.70	43.38	5.88	43.01	0.93	0.07	99.98	[284]
HG-C3-Barley (*Hordeum vulgare*)-Straw							
5.50	46.50	5.70	41.70	0.50	0.12	100.02	[44]
5.70	46.40	5.70	41.40	0.70	0.13	100.03	[44]
4.80	47.50	5.90	41.20	0.70	0.16	100.26	[50]
4.90	46.80	5.53	41.90	0.41	0.06	99.60	[56,148]
10.30	39.92	5.27	43.81	1.25		100.55	[108]
5.70	45.60	5.60	42.50	0.50	0.09	99.99	[261]
HG-C3-Cattails (*Typha* spp.)-Straw							
7.90	42.99	5.25	42.47	0.74	0.04	99.39	[108]
HG-C3-Esparto (*Macrochloa tenacissima*)-Straw							
2.20	46.94	6.44	43.56	0.86		100.00	[266]
HG-C3-Giant Cane (*Arundo donax*)-Straw							
5.45	40.37	7.09	46.05	0.76	0.19	99.90	[286]
3.06	39.07	5.14	51.50	0.39	0.07	99.22	[177]
3.43	47.06	5.84	42.95	0.60	0.12	100.00	[37]
4.30	45.75	6.12	42.66		0.27	99.10	[100]
HG-C3-Oat (*Avena sativa*)-Husk							
4.91	46.00	5.91	43.49	1.13	0.15	101.59	[111]
HG-C3-Oat (*Avena sativa*)-Straw							
5.90	47.60	5.80	43.50	0.50		103.30	[39,40,239]
5.88	46.20	5.70	41.54	0.60	0.08	100.00	[44,59]
7.80	46.30	4.90	38.70	0.69	0.11	98.50	[56]
4.90	46.00	5.91	43.50	1.13	0.02	101.46	[148]
8.85	45.00	5.70	38.91	1.40	0.14	100.00	[29,44,59]
4.10	45.80	6.10	42.90	1.00	0.10	100.00	[80]
10.70	44.20	5.50	38.80	0.80	0.09	100.09	[89]
3.10	48.20	6.00	41.60	1.10	0.12	100.12	[89]
HG-C3-Reed canary grass (*Phalaris arundinacea*)-Straw							
8.60	44.90	5.70	39.60		0.20	99.00	[100]
7.10	45.00	5.40	41.50	0.40	0.07	99.47	[101]
9.10	44.00	5.30	40.70	0.40	0.07	99.57	[101]
3.10	46.00	5.90	43.90	0.60	0.08	99.58	[101]
7.40	45.00	5.40	41.50	0.30	0.07	99.67	[101]
9.20	44.00	5.20	40.90	0.40	0.08	99.78	[101]
3.00	47.00	5.70	43.90	0.60	0.07	100.27	[101]
6.40	45.86	5.71	40.25	1.31	0.19	99.72	[128]
6.70	46.00	5.60	41.00	0.70	0.07	100.07	[131]
4.71	48.07	6.21	40.25	0.76		100.01	[242,275]
8.90	45.00	5.70	38.90	1.40	0.14	100.04	[270]
HG-C3-Rice (*Oryza sativa*)-Husk							
20.26	38.83	4.75	35.59	0.52	0.05	100.00	[37,217]
22.60	47.80	5.10	38.90	0.10		114.50	[41,184]

15.61	42.36	5.07	36.12	0.77	0.07	100.00	[55,271]
22.89	34.94	5.46	38.86	0.11		102.26	[90,184]
17.86	40.96	4.30	35.86	0.40	0.02	99.40	[108]
17.37	41.38	5.15	35.50	0.51	0.08	100.00	[109]
20.97	38.86	4.86	37.15	0.42	0.06	102.32	[111]
20.60	38.30	4.36	35.45	0.83	0.06	99.60	[114]
18.64	38.92	5.12	36.77	0.55	0.00	100.00	[26,114]
15.80	38.92	5.10	37.89	2.17	0.12	100.00	[26,114,193]
22.20	36.42	4.91	35.88	0.59		100.00	[124]
19.07	37.07	4.86	38.77	0.24	0.00	100.00	[137]
15.50	38.50	5.70	39.80	0.50		100.00	[149,179]
21.10	37.80	5.00	35.40	0.55	0.05	99.90	[158]
26.20	35.60	4.50	33.40	0.19	0.02	99.91	[158]
14.10	43.10	4.90	37.30	0.50	0.10	100.00	[162]
16.69	37.03	5.25	40.94	0.09		100.00	[163]
23.50	38.90	5.10	32.00	0.60		100.10	[176]
18.20	42.60	5.10	33.44	0.51	0.02	99.87	[187]
24.60	38.70	4.70	31.37	0.50	0.01	99.88	[187]
18.80	42.10	4.98	33.66	0.40	0.02	99.96	[187]
20.00	37.60	5.42	36.56	0.38	0.03	99.99	[187,194]
18.80	40.68	5.03	35.16	0.32	0.08	100.08	[188]
21.24	38.50	5.20	34.61	0.45		100.00	[26]
7.68	43.04	6.92	39.75	2.29	0.31	100.00	[195]
9.99	46.57	4.61	39.04	0.73	0.12	101.06	[62,210,274]
12.80	42.30	6.10	37.50	1.10	0.04	99.84	[211]
16.20	41.64	6.15	35.06	0.61	0.34	100.00	[218]
21.78	37.90	4.82	34.90	0.43	0.17	100.00	[224]
17.90	40.73	4.90	36.19	0.24	0.04	100.00	[233]
14.20	40.10	5.80	39.10	0.70	0.05	99.95	[235]
9.96	46.60	4.60	39.10	0.70	0.10	101.06	[236]
15.20	42.99	5.43	35.62	0.76	0.05	100.05	[249]
16.94	46.17	4.83	31.64	0.40	0.02	100.00	[255]
19.27	38.90	5.10	37.90	2.17	0.12	103.46	[276]
HG-C3-Rice (*Oryza sativa*)-Straw							
18.67	38.24	5.20	36.84	0.87	0.18	100.00	[37,51,82]
22.10	41.62	3.85	31.60	0.59	0.06	99.83	[52]
19.10	38.90	4.74	35.30	1.37	0.11	99.52	[56]
18.63	37.95	4.80	37.30	0.52	0.09	99.29	[73]
22.10	41.62	3.85	39.24	0.59	0.06	107.47	[79]
17.12	40.94	5.70	34.87	1.15	0.22	100.00	[81]
20.87	37.87	4.61	35.82	0.63	0.14	99.94	[83,165]
7.60	44.00	5.90	42.00	0.63	0.17	100.30	[84]
13.42	41.78	4.63	36.57	0.70	0.08	97.18	[108,114]
24.36	34.60	3.93	35.38	0.93	0.16	99.36	[108]
16.82	39.75	4.93	37.38	0.94	0.19	100.00	[109]
15.50	35.97	5.28	43.08	0.17		100.00	[117,118]
13.39	40.89	4.53	39.36	1.14	0.69	100.00	[134,138]
25.51	36.90	4.70	32.50	0.30	0.06	99.97	[141]
13.40	41.80	4.63	36.60	0.70	0.08	97.21	[148]
19.40	40.44	5.31	34.07	0.66	0.12	100.00	[149,179]
19.80	36.90	5.00	37.90	0.40		100.00	[176]
20.38	35.68	4.62	39.14	0.28		100.10	[26]
22.10	38.50	3.60	34.60	0.60	0.10	99.50	[201]
11.48	42.95	6.75	36.56	1.54	0.72	100.00	[218]
7.60	43.85	5.88	41.87	0.63	0.17	99.99	[84,242]
14.60	41.93	5.64	36.66	1.09	0.08	100.00	[283]
HG-C3-Rye (*Secale cereale*)-Straw							
4.60	47.50	5.29	41.70	0.46	0.06	99.61	[56]
HG-C3-Tobacco (*Nicotiana* spp.)-Leaves							
19.20	41.20	4.90	33.90	0.90	0.00	100.10	[47]
HG-C3-Tobacco (*Nicotiana* spp.)-Straw							
2.60	49.30	5.60	42.80	0.70	0.00	101.00	[47]
7.54	40.60	5.70	39.68	0.80	0.49	94.81	[164]
10.90	35.25	4.32	46.60	2.83	0.10	100.00	[166,169]
10.39	45.78	5.70	38.87	2.77	0.62	104.13	[174]
15.64	37.99	5.11	36.22	4.40	0.64	100.01	[174]
16.56	42.01	5.24	37.99	2.32	0.50	104.62	[174]
HG-C3-Wheat (*Triticum* spp.)-Stems							
5.90	46.40	5.67	40.80	0.69	0.10	99.56	[56]
HG-C3-Wheat (*Triticum* spp.)-Straw							
3.89	47.55	5.86	42.02	0.59	0.09	100.00	[37]
4.32	46.96	5.69	42.41	0.43	0.19	100.00	[37,217]
7.02	44.92	5.46	42.00	0.44	0.16	100.00	[37]
9.55	42.90	5.11	41.62	0.53	0.29	100.00	[37]
13.70	41.80	5.50	35.50	0.70		97.20	[41]
3.50	47.20	5.90	41.50	0.50	0.13	98.73	[44,50]
6.10	46.50	5.70	40.10	1.40	0.12	99.92	[44,50]
4.90	47.30	5.80	41.40	0.50	0.07	99.97	[44]
5.40	46.90	5.80	40.90	0.80	0.18	99.98	[44]
4.70	47.30	5.87	41.49	0.58	0.07	100.01	[44,59]

5.30	46.90	5.80	41.20	0.70	0.13	100.03	[44]
5.40	46.40	5.90	41.60	0.60	0.13	100.03	[44,50]
4.50	47.10	5.90	41.90	0.60	0.07	100.07	[44]
8.40	45.20	6.00	39.90	0.54	0.17	100.21	[50]
9.80	47.52	5.53	36.33	0.63	0.13	99.94	[52]
5.00	46.00	5.50	41.40	1.65	0.10	99.65	[56]
22.80	36.80	4.81	33.10	1.02	0.27	98.80	[56]
18.90	38.60	5.07	36.30	1.07	0.29	100.23	[56]
12.78	42.49	5.12	38.68	0.68	0.39	100.14	[73,83]
7.80	45.50	6.12	40.00	0.52	0.13	100.07	[74]
10.01	42.32	9.72	37.21	0.52	0.22	100.00	[81]
6.42	46.70	6.09	40.00	0.64	0.13	99.98	[84]
6.94	45.70	6.05	40.80	0.44	0.08	100.01	[84]
5.08	46.60	6.15	41.40	0.60	0.19	100.02	[84]
6.22	46.95	5.36	39.70	0.51	0.22	98.95	[85]
14.66	42.54	4.72	36.68	1.08	0.33	100.00	[86]
7.75	46.98	5.39	38.67	1.04	0.17	100.00	[86]
8.08	45.05	5.43	40.35	0.61	0.19	99.71	[87]
7.60	43.70	5.08	41.96	0.79	0.43	99.56	[88]
6.60	46.20	5.60	40.70	0.90	0.14	100.14	[89]
15.00	41.80	5.50	35.50	0.70		98.50	[41,47,90]
12.70	50.94	5.59	30.37	0.32	0.09	100.01	[91]
8.90	43.20	5.00	39.40	0.61	0.11	97.22	[90,108,114,171]
7.61	45.63	5.44	40.37	0.73	0.22	100.00	[109]
8.35	45.21	6.01	39.87	0.56		100.00	[110]
13.50	45.50	5.10	34.10	1.80		100.00	[117,127]
4.10	43.89	6.54	44.54	0.42	0.51	100.00	[132]
6.10	46.10	5.60	41.70	0.50	0.08	100.08	[134,144]
7.40	45.30	5.89	40.54	0.68	0.19	100.00	[149,179]
9.00	43.70	5.58	40.91	0.62	0.19	100.00	[174]
11.20	47.50	5.40	35.80	0.10		100.00	[176]
6.90	42.95	5.35	46.99	0.00		102.19	[26]
8.13	41.40	5.70	42.90	1.10	0.50	99.73	[206]
6.55	45.95	6.07	40.12	0.71	0.12	99.52	[78,242]
5.08	46.59	6.15	41.39	0.60	0.19	99.99	[84,242]
4.65	46.95	6.10	41.86	0.44		100.00	[92,242]
7.90	45.60	5.70	40.00	0.70	0.09	99.99	[261]
4.90	47.30	5.80	41.20	0.50	0.10	99.80	[270]
4.50	47.10	5.90	41.80	0.60	0.10	100.00	[270]
6.25	45.69	4.65	42.63	0.46	0.31	100.00	[278]
HG-C3-Giant Cane (*Arundo donax*)-Bagasse							
3.70	47.70	6.00	41.94	0.50	0.16	100.00	[44,59]
HG-C4-Banagrass (*Pennisetum purpureum*)-Straw							
9.88	45.06	5.42	38.69	0.84	0.11	100.00	[37]
3.94	47.98	5.50	41.69	0.60	0.10	99.81	[83]
HG-C4-Corn (*Zea mays*)-Cob							
1.65	48.40	5.60	44.30	0.30		100.25	[90,183]
1.94	47.35	5.90	38.07	0.69	0.18	94.13	[93]
1.36	46.58	5.87	45.46	0.47	0.01	99.75	[108,114,117,120]
3.12	46.51	5.68	44.13	0.47	0.09	100.00	[109]
3.48	48.22	6.20	42.94	1.57	0.13	102.54	[111]
1.00	49.00	5.40	44.60	0.40		100.40	[41,117,127]
1.20	41.44	5.96	51.26	0.14		100.00	[124]
2.10	42.90	6.40	47.71	0.60	0.29	100.00	[132]
3.29	44.55	4.55	47.14	0.43	0.04	100.00	[134,142]
5.34	46.30	5.60	42.19	0.57	0.00	100.00	[148,149,179]
2.24	42.90	6.40	45.46	0.60	0.29	97.89	[164]
2.80	47.60	5.00	44.60	0.00		100.00	[176]
8.81	45.12	6.58	38.63	0.68	0.17	100.00	[218]
HG-C4-Corn (*Zea mays*)-Straw							
7.70	44.95	5.91	40.70	0.65	0.07	99.98	[29,45]
3.90	49.40	5.60	42.50	0.60	0.10	102.10	[47]
8.50	44.60	5.37	39.60	0.41	0.05	98.53	[56]
5.10	46.80	5.74	41.40	0.66	0.11	99.81	[56]
5.00	42.50	5.04	42.60	0.75	0.18	96.07	[41,90,183]
11.40	46.23	5.34	35.98	0.85	0.06	99.87	[91]
4.88	46.60	4.99	40.05	0.79	0.22	97.53	[93]
6.23	37.84	4.98	49.82	1.05	0.08	100.00	[94]
6.73	45.48	5.52	41.52	0.69	0.04	99.98	[95]
5.70	47.00	5.80	40.90	0.60	0.10	100.10	[96]
5.58	43.65	5.56	43.31	0.61	0.01	98.72	[108,114,169,171]
7.02	44.77	5.39	41.76	0.85	0.21	100.00	[109]
7.40	46.50	5.81	39.67	0.56	0.11	100.05	[114]
6.40	43.86	5.77	43.24	1.28	0.05	100.60	[114]
5.86	44.10	6.15	44.50	0.49	0.10	101.20	[115]
6.40	45.53	6.15	41.11	0.78	0.13	100.10	[148]
6.40	45.43	6.15	41.11	0.78	0.13	100.00	[149,179]
5.60	43.70	5.56	43.30	0.61	0.01	98.78	[159,160]
8.18	47.40	5.01	38.09	0.77	0.31	99.76	[159]
7.30	46.50	5.81	39.70	0.56	0.11	99.98	[159,161]

6.90	39.70	5.90	44.86	1.50	0.29	99.15	[164]
2.90	45.54	5.24	46.03	0.19	0.06	99.96	[169,170]
10.81	44.61	5.54	37.80	1.24		100.00	[173]
6.80	41.90	5.30	46.00	0.00		100.00	[176]
6.80	44.92	4.68	41.38	2.11	0.11	100.00	[253]
5.08	43.51	6.23	41.70	1.52	0.16	98.20	[258]
6.00	47.28	5.06	40.63	0.80	0.22	99.99	[280]
7.65	44.73	5.87	40.44	0.60	0.07	99.36	[212]
HG-C4-Indiangrass (*Sorghastrum nutans*)-Straw							
4.15	47.30	6.01	42.18	0.34	0.04	100.02	[37]
HG-C4-Kentucky bluegrass (*Poa pratensis*)-Straw							
5.49	48.96	5.48	26.82	12.92	0.34	100.01	[133]
HG-C4-Millet (*Pennisetum glaucum*)-Husk							
8.40	40.56	5.24	45.50	0.40		100.10	[26]
HG-C4-Millet (*Pennisetum glaucum*)-Straw							
5.27	43.71	5.85	45.16	0.01	0.00	100.00	[26,114]
HG-C4-Miscanthus (*Miscanthus* spp.)-Straw							
3.36	47.66	5.75	42.43	0.45	0.05	99.70	[37]
3.05	47.29	5.75	43.52	0.33	0.06	100.00	[37,44]
3.31	47.90	6.00	41.64	0.60	0.55	100.00	[44,59]
2.30	48.60	6.00	42.72	0.30	0.08	100.00	[44,59]
1.50	48.10	5.80	41.90	0.30	0.10	97.70	[57]
1.10	49.00	6.00	43.80	0.60	0.10	100.60	[57]
4.80	47.90	5.50	41.00	0.54	0.11	99.85	[56]
1.50	48.40	6.30	43.30	0.30	0.10	99.90	[61]
9.30	39.80	5.07	44.20	1.07	0.05	99.49	[56]
1.10	49.00	6.05	43.81		0.02	99.98	[100]
4.90	50.70	4.40	39.10	0.30	0.15	99.55	[107]
4.00	47.04	6.14	42.24	0.67	0.19	100.29	[128]
3.00	43.70	5.70	44.80	1.10	0.20	98.50	[286]
HG-C4-Napier grass (*Pennisetum purpureum*)-Straw							
5.70	45.20	6.00	42.30	0.00		99.20	[114]
HG-C4-Sorghum (*Sorghum bicolor moench*)-Straw							
6.88	46.07	5.76	40.63	0.39	0.27	100.00	[109]
HG-C4-Sudan Grass (*Sorghum bicolor subsp. drummondii*)-Straw							
8.65	44.58	5.35	39.18	1.21	0.08	99.05	[108,114,117,120]
HG-C4-Sugarcane (*Saccharum* spp.)-Bagasse							
2.44	48.64	5.87	42.85	0.16	0.04	100.00	[37,73,217,262]
3.80	45.90	5.68	42.90	1.73		100.01	[58]
8.45	45.20	5.48	40.67	0.13	0.05	99.98	[83]
10.07	44.62	5.92	39.13	0.25	0.00	99.99	[98,282]
12.60	38.30	6.04	41.35	1.71	0.00	100.00	[98,282]
11.27	44.80	5.35	39.55	0.38	0.01	101.36	[26,41,108,114,120]
8.03	45.71	5.89	40.37	0.00	0.00	100.00	[114]
13.30	39.70	5.50	42.30	0.30		101.10	[114]
2.44	48.64	5.87	42.82	0.16		99.93	[25,125]
7.00	44.40	6.50	42.00	0.20		100.10	[125,126]
1.33	48.58	5.97	38.94	0.20	0.05	95.07	[141]
1.28	47.96	5.89	38.44	0.20	0.05	93.82	[151,153]
5.18	55.13	5.74	32.78	0.65	0.18	99.66	[151,154]
1.60	48.81	5.90	43.10	0.49	0.10	100.00	[151,152]
1.60	45.56	6.20	46.44	0.20		100.00	[151,155]
4.14	46.66	6.42	42.27	0.43	0.08	100.00	[151]
3.30	48.10	5.90	42.40	0.15	0.02	99.87	[158]
4.00	47.00	6.50	42.50	0.00		100.00	[163]
2.90	43.80	5.80	47.10	0.40		100.00	[176]
3.20	45.48	5.96	45.21	0.15		100.00	[26]
0.97	49.52	5.81	43.38	0.22	0.11	100.00	[145,202]
3.00	48.96	6.69	41.12	0.22		100.00	[218]
2.15	41.10	6.44	49.90	0.25	0.16	100.00	[224]
9.11	45.17	5.54	39.81	0.30	0.06	100.00	[240]
4.48	47.92	5.76	41.52	0.30	0.03	100.01	[245]
8.70	50.00	6.00	34.00	1.10	0.10	99.90	[270]
15.20	42.40	5.20	36.80	0.30	0.03	99.93	[270]
HG-C4-Sugarcane (*Saccharum* spp.)-Leaves							
7.70	39.75	5.55	46.82	0.17		99.99	[117,118]
7.70	39.80	5.50	46.80	0.19		99.99	[157]
HG-C4-Sweet sorghum (*Sorghum bicolor*)-Bagasse							
5.90	48.00	5.27	39.10	1.69	0.09	100.05	[58]
HG-C4-Sorghum (*Sorghum vulgare*)-Straw							
4.74	47.30	5.80	41.67	0.40	0.09	100.00	[29,44,59]
6.80	46.80	4.82	39.80	1.35	0.07	99.64	[56]
HG-C4-Switchgrass (*Panicum virgatum*)-Leaves							
8.60	42.10	6.50	42.10	0.67	0.05	100.02	[231]
1.80	45.80	6.60	45.50	0.21	0.02	99.93	[231]
HG-C4-Switchgrass (*Panicum virgatum*)-Stems							
5.60	43.70	6.50	43.60	0.51	0.06	99.97	[231]
2.00	46.00	6.50	45.10	0.30	0.05	99.95	[231]
HG-C4-Switchgrass (*Panicum virgatum*)-Straw							
8.97	46.68	5.82	37.57	0.77	0.19	100.00	[37,73,82]

2.69	47.51	5.80	43.60	0.36	0.04	100.00	[37]
3.61	47.45	5.75	42.37	0.74	0.08	100.00	[37,217]
5.10	47.17	5.79	41.19	0.66	0.10	100.01	[29,37]
8.98	46.68	5.82	37.38	0.76	0.19	99.81	[41,182]
10.10	47.80	5.76	35.10	1.17	0.10	100.03	[56]
10.60	42.20	5.39	41.20	0.46	0.10	99.95	[56]
3.77	45.12	6.48	44.23	0.31	0.08	99.99	[83]
8.00	46.50	5.35	39.29	0.65	0.09	99.88	[91]
4.60	48.00	5.40	41.40	0.41	0.16	99.97	[102]
5.60	47.30	5.30	41.10	0.54	0.13	99.97	[102]
4.40	48.00	5.40	41.70	0.42	0.14	100.06	[102]
4.59	46.86	5.84	42.02	0.58	0.11	100.00	[103]
4.36	47.58	5.45	42.17	0.40	0.06	100.02	[104]
4.25	47.42	5.67	42.43	0.35	0.21	100.33	[105]
5.33	47.28	5.59	41.64	0.39	0.17	100.40	[105]
6.65	46.82	5.66	40.42	0.70	0.23	100.48	[105]
6.73	47.00	5.47	40.41	0.67	0.24	100.52	[105]
4.30	42.84	5.55	46.92	0.29		99.90	[106]
5.70	47.00	5.30	41.40	0.50	0.10	100.00	[134,147]
3.73	46.53	5.84	42.89	0.46	0.55	100.00	[242,275]
WB-Deciduous-African Teak (*Chlorophora excelsa*)-Wood							
2.80	50.70	6.00	40.40	0.20	0.00	100.10	[268]
WB-Deciduous-Agba (*Gossweilerodendron balsamiferum*)-Wood							
0.40	50.40	6.20	42.50	0.50	0.01	100.01	[268]
WB-Deciduous-Ailanthus (*Ailanthus* spp.)-Wood							
1.70	49.50	6.20	41.00	0.30		98.70	[127]
WB-Deciduous-Alder (*Alnus incana*)-Wood							
0.30	48.27	6.02	45.11	0.30	0.05	100.05	[111]
0.40	49.55	6.06	43.78	0.13	0.07	99.99	[114]
WB-Deciduous-Almond (*Prunus dulcis*)-Fruit-res							
6.13	47.53	5.97	39.18	1.13	0.06	100.00	[37,82]
3.29	49.30	5.97	40.64	0.76	0.04	100.00	[37]
3.30	47.90	6.00	41.70	1.10	0.00	100.00	[41,47,127,202,220]
6.20	46.50	5.45	41.00	0.71	0.03	99.89	[56]
0.94	49.70	6.30	42.79	0.26	0.01	100.00	[66]
3.00	50.10	5.95	40.10	0.74	0.03	99.92	[56]
6.20	46.50	5.97	40.10	1.15	0.04	99.96	[56]
3.30	47.90	6.00	41.60	1.10	0.06	99.96	[72]
5.78	45.79	5.36	40.60	0.96	0.01	98.50	[108,114]
4.81	44.98	5.97	42.27	1.16	0.02	99.21	[90,108,114]
1.03	49.94	5.79	45.01	0.17	0.01	101.95	[111]
0.62	50.50	6.60	42.68	0.21	0.01	100.62	[71]
WB-Deciduous-Almond (*Prunus dulcis*)-Log-res							
1.63	51.30	5.29	40.90	0.66	0.01	99.79	[108,114,117,120]
1.34	50.61	6.41	40.84	0.76	0.03	100.00	[71]
WB-Deciduous-Apricot (*Prunus armeniaca* L.)-Fruit-res							
0.19	44.31	5.73	49.36	0.37	0.05	100.00	[166]
WB-Deciduous-Apricot (*Prunus armeniaca* L.)-Log-res							
0.20	51.40	6.29	41.20	0.80	0.10	99.99	[148]
WB-Deciduous-Babylon Willow (*Salix babilonica*)-Wood							
2.40	47.20	5.60	44.40	0.40	0.00	100.00	[268]
WB-Deciduous-Beech (*Fagus* spp.)-Bark							
7.80	47.39	5.53	38.54	0.65	0.10	100.01	[29,38]
WB-Deciduous-Beech (*Fagus* spp.)-Wood							
1.00	48.80	6.00	44.50	0.14	0.02	100.46	[56]
0.56	48.10	6.40	44.82	0.08		99.96	[77]
0.34	48.70	5.70	45.00	0.13	0.05	99.92	[107]
0.65	51.64	6.26	41.45	0.00	0.00	100.00	[114]
1.40	49.50	6.20	41.20	0.40		98.70	[41,127]
0.80	48.27	6.36	45.20	0.14		100.77	[134]
0.50	52.30	6.10	41.00	0.50		100.40	[175]
0.50	42.20	5.50	52.30	0.03	0.00	100.53	[235]
0.30	50.15	5.28	44.27	0.00	0.00	100.00	[244]
0.20	50.20	4.89	44.71	0.00	0.00	100.00	[249]
0.50	45.87	4.98	48.66	0.03	0.00	100.03	[249]
0.50	46.70	5.90	46.80	0.20	0.02	100.12	[268]
WB-Deciduous-Birch (*Betula* spp.)-Bark							
2.10	55.80	6.56	34.95	0.49	0.10	100.00	[29,38]
WB-Deciduous-Birch (*Betula* spp.)-Wood							
0.37	48.70	6.40	44.50	0.08		100.05	[44,77]
0.20	48.07	6.00	45.56	0.17	0.05	100.05	[111]
0.86	50.12	3.93	41.36	0.30		96.57	[250]
WB-Deciduous-Black Locust (*Robinia pseudoacacia*)-Log-res							
0.80	50.73	5.71	41.93	0.57	0.01	99.75	[108,114]
WB-Deciduous-Brazil Nut (*Bertholletia excelsa*)-Fruit-res							
1.70	49.16	5.70	42.77	0.69		100.03	[219]
WB-Deciduous-Castanea (*Castanea sativa*)-Wood							
0.10	47.10	4.90	47.70	0.20	0.02	100.02	[268]
WB-Deciduous-Cherry (*Prunus* spp.)-Fruit-res							
0.25	51.80	6.10	41.60	0.25		100.00	[277]

WB-Deciduous-Chestnut (*Castanea* spp.)-Wood							
0.40	45.50	5.70	48.20	0.20	0.00	100.00	[257]
WB-Deciduous-Chinese walnut (*Juglans mandshurica Maxim*)-Wood							
1.70	47.37	7.07	43.66	0.19	0.02	100.00	[233]
WB-Deciduous-Courbaril (*Hymenaea courbaril*)-Wood							
0.70	48.30	5.70	45.10	0.20	0.04	100.04	[268]
WB-Deciduous-Elm (*Ulmus* spp.)-Bark							
8.10	46.78	5.33	39.06	0.64	0.10	100.01	[29,38]
WB-Deciduous-English oak (*Quercus robur*)-Wood							
0.30	47.20	5.50	46.80	0.20	0.01	100.01	[268]
WB-Deciduous-Fraxinus (*Fraxinus angustifolia*)-Wood							
0.40	47.70	6.10	45.60	0.20	0.04	100.04	[268]
WB-Deciduous-Grape (*Vitis vinifera*)-Log-res							
2.51	48.02	5.89	41.93	0.86	0.07	99.28	[108,114]
2.17	46.59	5.85	43.90	0.83	0.04	99.38	[108,114,117,120]
2.45	47.77	5.82	42.63	0.75	0.03	99.45	[108]
2.25	47.35	5.77	43.32	0.77	0.01	99.47	[108]
2.71	47.14	5.82	43.03	0.86	0.01	99.57	[108]
2.06	46.97	5.80	44.49	0.67	0.01	100.00	[46,134]
5.22	44.89	6.74	43.04	0.11	0.00	100.00	[202,203]
4.32	48.10	5.44	41.32	0.79	0.04	100.01	[241]
7.10	43.57	5.30	43.45	0.54	0.05	100.00	[260]
WB-Deciduous-Hazelnut (*Corylus* spp.)-Fruit-res							
1.30	50.80	5.60	41.10	1.00	0.00	99.80	[41,47]
1.40	51.60	6.20	40.20	1.60	0.04	101.04	[72,220]
1.40	52.90	5.60	42.70	1.40		104.00	[72,90,117,127]
1.80	51.00	5.40	42.30	1.30		101.80	[127]
2.50	52.20	5.80	42.70	1.30		104.50	[175]
7.00	50.96	6.23	34.78	0.93	0.09	100.00	[215]
1.42	50.08	5.13	42.00	1.38		100.00	[251]
4.30	44.31	5.55	45.46	0.38		100.00	[279]
WB-Deciduous-Hickory (*Carya* spp.)-Wood							
0.73	47.67	6.49	43.11	0.00	0.00	98.00	[114]
WB-Deciduous-Jujuba (*Ziziphus zizyphus*)-Wood							
2.32	47.63	6.12	43.78	0.15		100.00	[26]
WB-Deciduous-Maple (*Acer* spp.)-Bark							
4.00	49.92	5.95	39.65	0.38	0.11	100.01	[29,38]
WB-Deciduous-Maple (*Acer* spp.)-Wood							
1.35	50.64	6.02	41.74	0.25	0.00	100.00	[114]
1.00	46.80	5.80	46.10	0.20	0.06	99.96	[268]
WB-Deciduous-Mulberry (*Morus* spp.)-Log-res							
2.10	44.23	6.61	46.25	0.51		99.70	[117,118]
WB-Deciduous-Oak (*Quercus* spp.)-Bark							
5.30	49.81	5.40	39.30	0.09	0.09	100.00	[75]
5.30	49.70	5.40	39.30	0.20	0.10	100.00	[26,122]
WB-Deciduous-Oak (*Quercus* spp.)-Log-res							
1.67	47.81	5.93	44.12	0.12	0.01	99.66	[108]
1.52	49.48	5.38	43.13	0.35	0.01	99.87	[108,114]
3.00	47.16	6.32	40.91	2.50	0.10	100.00	[226]
2.07	47.56	6.67	41.26	2.34	0.10	100.00	[226]
4.05	46.79	6.09	40.28	2.70	0.10	100.00	[226]
WB-Deciduous-Oak (*Quercus* spp.)-Wood							
0.31	49.96	5.92	43.77	0.03	0.01	100.00	[37]
1.21	51.47	5.61	41.50	0.20	0.02	100.00	[86]
0.19	50.13	5.98	44.76	0.08	0.03	101.17	[111]
0.30	49.68	5.93	44.03	0.07	0.01	100.02	[114]
0.80	38.95	4.97	55.13	0.11	0.04	100.00	[221]
0.42	48.00	6.28	45.07	0.23	0.00	100.00	[234]
0.26	49.74	5.51	45.26	0.31	0.01	101.10	[250]
WB-Deciduous-Peach (*Prunus persica*)-Fruit-res							
1.03	53.00	5.90	39.14	0.32	0.05	99.44	[41,90,108,114]
1.10	49.14	6.34	43.52	0.48	0.02	100.60	[114,117,119]
0.65	51.95	5.76	40.70	0.79	0.01	99.86	[134,143]
1.00	53.00	5.90	39.10	0.32	0.05	99.37	[148]
5.85	55.27	4.56	34.75	0.84	0.09	101.36	[111]
WB-Deciduous-Pistachio (*Pistacia vera*)-Fruit-res							
1.41	50.20	6.32	41.16	0.69	0.22	100.00	[37]
1.40	50.20	6.30	41.20	0.68	0.22	100.00	[56]
1.13	48.79	5.91	43.41	0.56	0.01	99.81	[108,114,117,120]
WB-Deciduous-Plum (*Prunus* spp.)-Fruit-res							
1.40	49.20	6.61	41.81	0.89	0.08	99.98	[29]
WB-Deciduous-Poplar (*Populus* spp.)-Bark							
2.20	52.42	6.55	38.44	0.29	0.10	100.00	[29,38]
1.29	45.96	5.61	46.46	0.68		100.00	[265]
WB-Deciduous-Poplar (*Populus* spp.)-Wood							
2.70	50.18	6.06	40.44	0.60	0.02	100.00	[37]
1.60	50.82	5.89	41.08	0.59	0.02	100.00	[37]
2.10	50.52	5.97	40.82	0.59	0.02	100.02	[29,37]
1.33	48.45	5.85	43.69	0.47	0.01	99.80	[90,108,114]
0.65	51.64	6.26	41.45	0.00	0.00	100.00	[114]

4.33	47.89	5.67	41.89	0.22	0.11	100.11	[145]
4.33	47.89	5.67	41.89	0.22	0.00	100.00	[202]
0.92	50.88	6.04	41.90	0.17	0.09	100.00	[204]
3.40	47.33	6.18	42.60	0.42	0.07	100.00	[247]
2.70	47.68	6.23	42.85	0.49	0.06	100.00	[247]
3.60	47.24	6.07	42.31	0.71	0.07	100.00	[247]
0.45	49.93	5.69	43.54	0.39	0.01	100.00	[250]
0.76	47.42	6.14	45.56	0.12		100.00	[265]
WB-Deciduous-Poplar Pannonia (*Populus × euramericana cv. Pannonia*)-Log-res							
1.40	48.31	6.31	43.58	0.39	0.02	100.02	[284]
WB-Deciduous-Populus (*Populus euro-americana*)-Wood							
0.50	47.80	6.00	45.40	0.20	0.03	99.93	[268]
WB-Deciduous-Prune (*Prunus* spp.)-Fruit-res							
1.41	49.26	6.59	41.83	0.84	0.07	100.00	[37]
0.50	49.73	5.90	43.57	0.32		100.02	[108]
WB-Deciduous-Red oak (*Quercus* spp.)-Wood							
0.50	50.00	6.00	42.40	0.30		99.20	[41,127]
1.30	50.00	6.00	42.40	0.30		100.00	[41,90]
WB-Deciduous-Sapele (*Entandrophragma cylindricum*)-Wood							
1.00	47.80	5.80	45.10	0.30	0.01	100.01	[268]
WB-Deciduous-Sapupira (*Bowdichia nitida*)-Wood							
0.10	52.30	6.10	41.30	0.20	0.03	100.03	[268]
WB-Deciduous-Shea (*Vitellaria paradoxa*)-Fruit-res							
5.00	48.56	5.82	37.64	2.88	0.10	100.00	[98]
7.14	48.81	5.60	35.83	2.62		100.00	[110]
7.53	50.16	6.08	33.01	3.22	0.28	100.28	[130]
WB-Deciduous-Shorea (*Shorea* spp.)-Wood							
0.20	51.90	5.87	41.60	0.31	0.09	99.97	[214]
WB-Deciduous-Tree of heaven (*Ailanthus altissima*)-Log-res							
1.80	51.10	6.80	41.40	0.70	0.04	101.84	[284]
WB-Deciduous-Walnut (*Juglans* spp.)-Fruit-res							
2.36	53.65	6.50	36.05	1.34	0.10	100.00	[37]
2.95	53.51	6.52	35.38	1.53	0.11	100.00	[37]
2.80	53.50	6.60	45.40	1.50	0.10	109.90	[41]
2.80	53.50	6.60	35.50	1.50	0.10	100.00	[47,72,220]
0.56	49.98	5.71	43.35	0.21	0.01	99.82	[90,108,114]
2.02	49.95	5.87	42.52	0.62	0.13	101.11	[111]
1.20	49.81	5.64	42.94	0.41		100.00	[26]
WB-Deciduous-Walnut (*Juglans* spp.)-Log-res							
0.78	49.80	5.82	43.25	0.22	0.01	99.88	[108,114]
1.08	49.72	5.63	43.14	0.37	0.01	99.95	[108,114]
0.70	48.20	6.25	43.24	1.61		100.00	[117,118]
WB-Deciduous-Wild cherry (*Prunus avium*)-Wood							
0.10	48.60	5.80	45.30	0.20	0.05	100.05	[268]
WB-Deciduous-Willow (*Salix* spp.)-Log-res							
2.00	48.02	6.08	43.12	0.49	0.05	99.76	[128]
WB-Deciduous-Willow (*Salix* spp.)-Wood							
1.71	49.90	5.90	41.81	0.61	0.07	100.00	[37]
0.95	49.09	5.89	43.69	0.35	0.03	100.00	[37]
1.06	48.95	6.05	43.54	0.36	0.04	100.00	[37]
1.10	47.94	5.84	44.43	0.63	0.06	100.00	[37]
1.20	50.29	6.01	41.93	0.50	0.07	100.00	[37]
1.50	49.75	6.00	42.01	0.65	0.09	100.00	[37]
1.70	48.85	6.04	42.64	0.71	0.06	100.00	[37]
2.34	49.42	5.89	41.27	0.96	0.12	100.00	[37]
1.30	49.40	6.00	42.70	0.50	0.03	99.93	[44]
1.18	49.70	6.10	42.59	0.40	0.03	100.00	[44,59]
1.90	48.60	6.20	43.30		0.02	100.02	[48]
2.10	48.60	6.20	43.30		0.02	100.22	[48]
1.60	48.70	5.84	43.40	0.41	0.04	99.99	[56]
2.00	48.80	6.00	42.90	0.30	0.03	100.03	[89]
1.90	48.60	6.20	43.26		0.02	99.98	[100]
1.34	47.14	5.82	45.30	0.30		99.90	[106]
1.60	49.00	6.00	42.71	0.59	0.06	99.96	[29]
1.20	49.70	6.10	42.60	0.40	0.03	100.03	[270]
WB-Evergreen-Babassu (*Attalea speciosa*)-Fruit-res							
1.59	50.31	5.37	42.29	0.26	0.04	99.86	[108]
WB-Evergreen-Blue Gum (*Eucalyptus globulus*)-Wood							
0.50	46.20	5.80	47.20	0.20	0.02	99.92	[268]
WB-Evergreen-Cacao (*Theobroma cacao*)-Fruit-res							
10.50	47.40	5.24	33.60	3.03	0.19	99.96	[67]
WB-Evergreen-Camphor (*Cinnamomum camphora*)-Wood							
0.56	49.52	5.52	43.93	0.36	0.11	100.00	[134,146]
WB-Evergreen-Cashew (*Anacardium occidentale* L.)-Fruit-res							
1.90	56.00	6.90	34.70	0.44	0.05	99.99	[158]
2.00	56.90	7.00	33.60	0.45	0.04	99.99	[158]
WB-Evergreen-Casuarina (*Casuarina* spp.)-Wood							
1.40	48.61	5.83	43.36	0.59	0.02	99.81	[108,114]
1.83	48.50	6.04	43.32	0.31	0.00	100.00	[114]
1.83	48.50	6.24	43.12	0.31		100.00	[26]

WB-Evergreen-Cocoa (*Theobroma cacao*)-Fruit-res							
8.25	48.23	5.23	33.19	2.98	0.12	98.00	[108,114]
WB-Evergreen-Coconut (*Cocos nucifera*)-Fruit-res							
3.24	49.54	5.42	41.70	0.00	0.10	100.00	[29,53]
3.72	50.29	5.05	39.63	0.45	0.16	99.30	[108,114,117,120]
0.74	52.37	5.91	42.34	0.23	0.06	101.65	[111]
0.71	50.22	5.70	43.37	0.00	0.00	100.00	[26,114,191]
2.81	45.68	5.89	44.63	0.99		100.00	[163]
7.10	44.00	4.70	43.40	0.70		99.90	[176]
0.70	50.20	5.70	43.40	0.00		100.00	[176]
0.90	47.60	5.70	45.60	0.20		100.00	[176]
5.16	43.36	4.98	44.87	1.63		100.00	[26]
6.95	49.51	5.77	36.52	1.19	0.05	99.99	[178,242]
WB-Evergreen-Coconut (*Cocos nucifera*)-Wood							
11.50	42.40	5.13	40.80	0.03	0.04	99.90	[56]
WB-Evergreen-Coffee (*Coffea* spp.)-Fruit-res							
1.00	46.33	4.85	46.63	0.59	0.59	100.00	[29,53]
4.63	41.87	4.58	47.30	1.53	0.10	100.00	[53]
11.61	46.46	6.26	34.95	0.72		100.00	[124]
1.12	46.80	4.90	47.10	0.60	0.60	101.12	[134,137]
2.50	49.40	6.10	41.20	0.81	0.07	100.08	[158]
5.60	47.30	6.40	37.70	2.70	0.30	100.00	[216]
4.50	43.20	6.30	43.20	2.60	0.20	100.00	[257]
WB-Evergreen-Eucalyptus (*Eucalyptus* spp.)-Bark							
4.80	47.40	5.50	44.10	0.30		102.10	[39,40,239]
WB-Evergreen-Eucalyptus (*Eucalyptus* spp.)-Wood							
1.40	47.20	6.50	44.00	0.50	0.10	99.70	[57]
0.50	49.50	5.75	44.00	0.14	0.03	99.92	[56]
0.95	48.83	6.00	44.06		0.02	99.86	[100]
0.76	49.00	5.87	43.97	0.30	0.01	99.91	[108,114]
0.52	48.33	5.89	45.13	0.15	0.01	100.03	[108,114,117,120]
0.83	52.87	6.14	39.79	0.16	0.11	99.90	[111]
0.20	49.37	6.40	42.01	2.02		100.00	[117,118]
0.10	47.30	6.00	46.50	0.10		100.00	[117,123]
3.35	46.04	5.82	44.49	0.30		100.00	[26,117]
1.10	48.18	5.92	44.18	0.39	0.01	99.78	[26,108,114,120]
1.42	49.58	5.82	42.96	0.20	0.02	100.00	[213]
0.50	46.80	6.10	46.50	0.10	0.00	100.00	[257]
0.70	49.90	5.80	43.30	0.20	0.02	99.92	[270]
WB-Evergreen-Guayule (*Parthenium argentatum*)-Log-res							
3.15	55.19	6.35	34.36	0.65	0.20	99.90	[230]
12.80	47.09	5.23	32.88	1.38	0.62	100.00	[230]
WB-Evergreen-Hazelnut (*Olea europaea*)-Fruit-res							
1.50	52.80	5.60	42.60	1.40	0.04	103.94	[41]
1.45	55.76	5.60	37.99	0.34	0.03	101.17	[111]
WB-Evergreen-Leucaena (*Leucaena* spp.)-Wood							
2.50	47.90	5.84	43.30	0.41	0.08	100.03	[56]
5.11	45.95	6.06	41.23	2.42	0.27	101.04	[111]
WB-Evergreen-Macadamia (*Macadamia* spp.)-Fruit-res							
0.40	54.41	4.99	39.69	0.36	0.01	99.86	[108,114,117,120]
0.41	58.30	8.12	32.77	0.36	0.04	100.00	[111]
0.44	53.00	6.00	40.65	0.32	0.03	100.44	[240]
WB-Evergreen-Madrone (*Arbutus menziesii*)-Log-res							
0.57	48.00	5.96	44.95	0.06	0.02	99.56	[108]
WB-Evergreen-Madrone (*Arbutus menziesii*)-Wood							
0.20	48.94	6.03	44.75	0.05	0.02	99.99	[114]
0.30	48.56	6.05	45.08	0.05	0.02	100.06	[114]
WB-Evergreen-Mango (*Mangifera indica*)-Wood							
2.98	46.24	6.08	44.42	0.28		100.00	[26,114]
4.50	48.00	5.80	41.50	0.13	0.01	99.94	[158]
WB-Evergreen-Manzanita (*Arctostaphylos*)-Log-res							
0.82	48.18	5.94	44.68	0.17	0.02	99.81	[114]
WB-Evergreen-Neem (*Azadirachta indica*)-Wood							
1.93	48.26	6.27	43.46	0.08		100.00	[26]
WB-Evergreen-Oak (*Quercus chrysolepis*)-Wood							
0.50	47.84	5.80	45.76	0.07	0.01	99.98	[114,117,119]
WB-Evergreen-Oil palm (*Elaeis* spp.)-Fruit-res							
1.00	53.78	7.20	36.30	0.00	0.51	98.79	[150]
10.20	38.78	4.71	44.71	1.43	0.17	100.00	[248]
4.50	39.09	5.18	49.45	1.49	0.30	100.00	[248]
10.50	36.99	4.09	47.45	0.89	0.08	100.00	[248]
1.72	52.80	6.69	38.29	0.45	0.05	100.00	[37]
4.10	49.90	6.20	42.00	1.60	0.05	103.85	[41]
WB-Evergreen-Olive (*Olea europaea*)-Fruit-res							
3.10	51.16	6.40	38.18	1.07	0.07	99.97	[29,37,42,43]
7.20	54.20	5.38	31.74	1.30	0.21	100.03	[29,45]
1.50	37.80	6.23	53.60	0.71	0.03	99.87	[56]
2.60	51.30	5.82	39.00	1.00	0.28	100.00	[68]
4.60	50.70	5.89	36.97	1.36	0.30	99.82	[69,134,136]
6.30	50.00	6.50	36.30	0.80	0.10	100.00	[70]

3.30	52.80	6.70	36.70	0.50	0.05	100.05	[72]
2.39	47.80	5.10	45.40	0.10		100.79	[90,185]
3.16	48.81	6.23	43.48	0.36	0.02	102.06	[90,108]
3.20	48.81	6.23	43.48	0.36	0.01	102.09	[114]
3.60	48.20	5.98	40.68	1.54		100.00	[127]
9.83	49.07	6.15	33.69	1.26		100.00	[130]
23.19	39.46	4.85	31.38	1.11		100.00	[130]
7.90	50.04	6.63	34.15	1.28	0.12	100.12	[130]
3.90	42.57	5.62	47.91	0.00		100.00	[149,181]
4.00	49.92	6.14	38.50	1.44		100.00	[175]
3.90	42.57	5.62	47.91	0.00		100.00	[181]
14.46	47.70	6.14	29.65	2.05	0.00	100.00	[198]
2.52	45.33	6.24	45.52	0.39	0.00	100.00	[28]
10.10	40.53	4.70	41.38	2.79	0.50	100.00	[221]
8.15	46.66	5.56	35.03	4.44	0.17	100.00	[190,242]
3.46	46.91	5.53	42.54	1.52		99.95	[264]
WB-Evergreen-Olive (*Olea europaea*)-Leaves							
9.10	48.20	5.94	34.15	2.41	0.20	100.01	[168]
WB-Evergreen-Olive (*Olea europaea*)-Log-res							
3.67	47.50	6.00	43.66	1.06	0.04	101.93	[46]
12.00	40.68	5.73	40.95	0.59	0.07	100.02	[65]
9.80	52.00	6.91	29.40	1.62	0.18	99.91	[65]
2.80	47.00	6.00	43.20	1.00	0.03	100.03	[148]
2.24	51.10	6.57	38.79	1.16	0.14	100.00	[168]
1.39	56.17	6.53	35.55	1.20	0.16	101.00	[168]
WB-Evergreen-Olive (*Olea europaea*)-Wood							
3.20	47.43	5.23	43.46	0.68	0.03	100.03	[29,42,43]
1.06	45.12	6.12	39.68	0.00		91.99	[181]
3.00	49.80	6.00	40.40	0.70	0.06	99.96	[261]
5.50	47.00	5.90	40.80	0.70	0.10	100.00	[270]
WB-Evergreen-Palm (*Arecaceae* spp.)-Fruit-res							
5.20	48.35	6.16	37.45	2.56	0.26	99.97	[29,45]
8.33	47.21	6.05	36.76	1.38	0.28	100.00	[29,53]
4.44	48.85	7.04	36.99	2.68		100.00	[130]
11.80	52.20	7.10	28.00	0.70	0.07	99.87	[158]
4.60	51.50	5.70	37.70	0.36	0.03	99.89	[158]
3.02	48.79	7.33	40.18	0.00	0.68	100.00	[263]
2.21	53.78	7.20	36.30	0.00	0.51	100.00	[263]
2.35	65.90	8.28	21.55	1.57	0.34	100.00	[269]
5.14	48.34	6.20	37.44	2.62	0.26	100.00	[212]
WB-Evergreen-Palm (*Arecaceae* spp.)-Log-res							
7.80	45.60	5.60	39.30	0.19	0.16	98.65	[158]
WB-Evergreen-Palm (*Arecaceae* spp.)-Wood							
3.50	47.50	5.90	42.50	0.28	0.13	99.81	[158]
WB-Evergreen-Red gum (*Eucalyptus* spp.)-Wood							
8.04	52.69	4.60	34.48	0.10	0.05	99.96	[200]
WB-Evergreen-Redwood (*Sequoia sempervirens*)-Wood							
0.40	53.50	5.90	40.30	0.10	0.00	100.20	[114]
0.36	50.64	5.98	42.88	0.05	0.03	99.94	[117,120]
WB-Evergreen-She-oak (*Casuarina equisetifolia*)-Wood							
0.34	42.36	6.08	51.07	0.16		100.00	[267]
WB-Evergreen-Spotted gum (*Eucalyptus Maculata*)-Wood							
0.64	50.21	5.88	43.16	0.10	0.01	100.00	[245]
WB-Evergreen-Subabul (*Leucaena leucocephala*)-Wood							
0.90	48.20	5.90	45.10	0.00		100.10	[176]
1.12	46.24	5.80	46.59	0.25		100.00	[26]
1.20	48.15	5.87	44.75	0.03		100.00	[26,117,191]
WB-Evergreen-Tan Oak (*Lithocarpus densiflorus*)-Wood							
0.20	48.67	6.03	44.99	0.06	0.04	99.99	[114]
0.50	48.34	6.12	44.99	0.03	0.03	100.01	[114]
WB-Evergreen-Tasmanian (*Eucalyptus obliqua*)-Wood							
0.20	49.80	5.79	44.00	0.16	0.08	100.03	[214]
WB-Evergreen-Tea (*Camellia sinensis* L.)-Log-res							
1.40	48.60	5.50	39.50	0.50		95.50	[117,127]
1.70	47.67	6.13	43.16	1.33		99.99	[117,118]
WB-Evergreen-Tree heath (*Erica arborea*)-Log-res							
0.60	50.69	6.16	41.65	0.99		100.10	[149,180,181]
WN-Deciduous-Larch (*Larix* Mill.)-Wood							
0.12	44.18	6.38	49.32	0.12		100.12	[134,140]
WN-Deciduous-Tamarack (*Larix laricina*)-Bark							
4.20	54.61	9.77	30.66	0.67	0.11	100.01	[29,38]
WN-Evergreen-Cedar (*Cryptomeria japonica*)-Wood							
0.33	51.10	5.90	42.50	0.12	0.02	99.97	[135,141]
0.79	52.30	6.11	39.90	0.52	0.39	100.01	[205]
0.40	50.30	5.60	43.60	0.20	0.00	100.10	[268]
WN-Evergreen-Cypress (*Cupressus sempervirens*)-Wood							
0.70	51.60	6.20	40.40	0.65	0.46	100.01	[205]
WN-Evergreen-Douglas Fir (*Pseudotsuga menziesii*)-Bark							
1.20	56.20	5.90	36.70	0.00	0.00	100.00	[114,117,121]

WN-Evergreen-Douglas Fir (*Pseudotsuga menziesii*)-Wood							
0.80	52.30	6.30	40.50	0.10	0.00	100.00	[114]
0.10	50.64	6.18	43.00	0.06	0.02	100.00	[26,114,119]
0.40	47.60	5.90	45.80	0.20	0.01	99.91	[268]
WN-Evergreen-Fir (*Abies* spp.)-Bark							
2.60	52.60	6.04	38.47	0.19	0.10	100.00	[29,38]
WN-Evergreen-Fir (*Abies* spp.)-Log-res							
0.25	49.00	5.98	44.75	0.05	0.01	100.04	[108,114]
WN-Evergreen-Fir (*Abies* spp.)-Wood							
0.41	51.23	5.98	42.29	0.06	0.03	100.00	[37]
WN-Evergreen-Hemlock (*Tsuga canadensis*)-Bark							
2.50	53.63	5.75	37.83	0.20	0.10	100.00	[29,38]
WN-Evergreen-Hemlock (*Tsuga heterophylla*)-Wood							
2.20	50.40	5.80	41.10	0.10	0.10	99.70	[26,114,121]
0.40	51.80	6.20	40.60	0.60	0.38	99.98	[205,281]
WN-Evergreen-Japanese cedar (*Cupressus japonica*)-Bark							
2.50	51.77	5.56	39.59	0.59	0.10	100.10	[188]
WN-Evergreen-Japanese cedar (*Cupressus japonica*)-Wood							
0.20	50.70	6.19	42.81	0.10	0.00	100.00	[188]
WN-Evergreen-Pine (*Pinus pinaster*)-Wood							
0.20	48.40	6.00	45.30	0.10	0.00	100.00	[268]
WN-Evergreen-Pine (*Pinus* spp.)-Bark							
1.90	52.78	5.79	39.14	0.29	0.07	99.97	[29,38,44]
1.72	52.50	5.70	39.65	0.40	0.03	100.00	[44,59]
2.90	53.31	5.63	37.87	0.19	0.10	100.00	[75]
0.70	56.20	5.40	37.30	0.00	0.00	99.60	[114]
0.40	56.30	5.60	37.70	0.00	0.00	100.00	[114,117,122]
0.70	56.40	5.50	37.40	0.00	0.00	100.00	[114]
	55.49	5.56	37.74	0.17	0.09	99.05	[208]
4.05	44.33	4.70	46.42	0.48	0.02	100.00	[209]
5.73	53.86	5.39	34.76	0.24	0.02	100.00	[213]
5.21	51.36	5.96	35.92	0.31	1.05	99.81	[223]
1.20	53.15	5.63	39.60	0.40	0.02	100.00	[237]
WN-Evergreen-Pine (*Pinus pinea*)-Fruit-res							
1.52	49.80	6.17	42.13	0.34	0.04	100.00	[196]
WN-Evergreen-Pine (*Pinus pinaster*)-Leaves							
3.30	45.38	6.52	43.18	1.42	0.36	100.15	[168]
WN-Evergreen-Pine (*Pinus* spp.)-Log-res							
6.00	49.63	5.73	38.07	0.47	0.08	99.99	[29,45]
0.29	49.25	5.99	44.36	0.06	0.03	99.98	[108,114]
1.75	44.63	6.69	46.59	0.24	0.10	99.99	[168]
2.25	46.79	6.09	44.61	0.08	0.17	99.99	[168]
WN-Evergreen-Pine (*Pinus* spp.)-Wood							
0.08	51.00	5.99	42.82	0.08	0.00	99.97	[29,44,59]
2.20	52.20	5.77	39.70	0.10		99.97	[58]
0.30	49.70	6.20	43.70	0.10	0.02	100.02	[56]
0.10	49.10	6.40	44.00	0.20	0.20	100.00	[80]
0.31	51.90	6.00	41.80	0.10	0.01	100.12	[89]
0.30	49.41	6.11	44.07	0.11	0.05	100.05	[111]
0.40	51.30	6.13	42.00	0.12	0.02	99.97	[112]
0.40	50.50	6.10	42.80	0.20	0.03	100.03	[113]
1.31	52.60	7.00	40.10	0.00	0.00	101.01	[114]
0.55	50.54	7.08	41.11	0.15	0.57	100.00	[134,139,273]
1.72	50.38	4.46	42.29	0.69	0.46	100.00	[138]
0.36	50.08	6.70	42.51	0.16	0.20	100.00	[166]
0.30	49.25	6.18	44.17	0.30		100.20	[167]
0.23	53.80	7.93	38.04	0.00	0.00	100.00	[198]
0.10	52.00	6.07	41.55	0.28		100.00	[199]
0.59	50.91	6.13	42.14	0.23		100.00	[199]
0.99	49.89	5.96	43.05	0.11	0.00	100.00	[145,202]
2.91	49.65	7.06	39.91	0.25	0.22	100.00	[218]
0.85	39.58	5.17	54.13	0.08	0.19	100.00	[221,225]
0.41	50.84	6.04	42.55	0.11	0.05	100.00	[223]
0.40	51.10	6.00	42.80	0.10		100.40	[238]
0.40	49.99	5.81	43.52	0.10	0.18	100.00	[241]
0.17	53.21	6.19	40.23	0.10	0.10	100.00	[243]
0.32	49.30	6.44	42.53	0.19	0.04	98.84	[245]
0.50	49.35	6.17	43.98	0.03	0.00	100.03	[246]
0.34	48.09	5.17	46.14	0.25		100.00	[250]
3.03	52.03	5.97	40.08	0.41	0.07	101.59	[254]
0.70	49.65	5.53	43.92	0.10	0.10	100.00	[256]
0.20	45.20	6.30	48.20	0.10	0.00	100.00	[257]
0.90	50.05	6.05	42.50	0.48	0.03	100.00	[260]
5.60	47.20	5.70	39.20	2.20	0.09	99.99	[261]
3.80	44.10	5.90	45.50	0.70	0.00	100.00	[285]
0.70	48.28	7.31	43.41	0.25	0.23	100.18	[64]
5.95	49.66	5.67	38.07	0.51	0.08	99.94	[212]
WN-Evergreen-Radiata pine (*Pinus radiata*)-Wood							
0.30	50.10	6.07	43.20	0.21	0.08	99.96	[214]
0.43	50.18	5.47	43.89	0.02	0.01	100.00	[252]

WN-Evergreen-Spruce (*Picea* spp.)-Bark							
3.20	51.88	6.00	38.72	0.10	0.10	100.00	[29,38,44]
2.34	49.90	5.90	41.43	0.40	0.03	100.00	[44,59]
7.11	49.32	5.57	37.43	0.46	0.07	99.98	[76]
3.80	51.80	5.70	38.60		0.10	100.00	[114]
WN-Evergreen-Spruce (*Picea* spp.)-Log-res							
6.40	49.40	5.60	38.30	0.30	0.03	100.03	[89]
2.20	51.20	5.80	40.40	0.40	0.03	100.03	[89]
WN-Evergreen-Spruce (*Picea* spp.)-Wood							
0.90	51.40	6.10	41.20	0.30	0.00	99.90	[47]
0.30	48.91	6.02	44.65	0.12	0.05	100.05	[111]
1.50	51.90	6.10	40.90	0.30		100.70	[41,117,127]
0.40	52.00	6.20	41.20	0.40		100.20	[175]
0.98	51.07	5.84	42.02	0.08	0.00	100.00	[232]
WN-Evergreen-Sugar pine (*Pinus lambertiana*)-Wood							
0.30	52.20	6.14	41.10	0.22	0.07	100.03	[214]
0.32	52.30	6.20	41.20	0.22	0.08	100.32	[240]
WN-Evergreen-White pine (*Pinus monticola*)-Wood							
0.40	52.44	6.37	40.60	0.10	0.10	100.00	[222]

BA = Bamboo, HD = Herbaceous dicot, HG = Herbaceous grass, WB = Broad-leaved wood, and WN = Needle-leaved wood.

[a] Group-Ecotype-Species (Latin name)-Assortment.

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